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Journal
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Vol. 9 DECEMBER, 1924 Number 6

NOTE ON THE LEAST MECHANICAL EQUIVALENT OF LIGHT

By Herbert E. Ives

The value of the least mechanical equivalent of light is fixed immediately we know the radiant value of some radiation of known luminous efficiency, where luminous efficiency is measured on the scale in which maximum possible luminous efficiency is rated as unity. Thus, as an illustration may be taken the determination of the constant in question performed by the writer and his associates several years ago[1] in which the luminous value and the radiant value of the monochromatic green radiation of the mercury arc (λ5461) were simultaneously measured. The watts per lumen of this radiation were found to be .00163. This value multiplied by the luminous efficiency of this wave length, which is very close to unity, gives at once the least mechanical equivalent of light. The exact value, as derived from this earlier investigation by using the latest data for luminous efficiency, will be discussed later in the paper.

It is not, however, necessary to use a monochromatic radiation for this purpose. A complex radiation may be used provided all of its elements are given their proper rating in luminous efficiency. A particularly valuable opportunity for determination of the least mechanical equivalent of light is furnished by the *black body*, once the luminous value of its radiation at some accurately determined temperature is established, since its radiation is accurately expressed by a well verified formula.

[1] "The Mechanical Equivalent of Light"—Ives, Coblentz and Kingsbury—Phys. Rev. p. 269; April, 1915.

The equation connecting the various quantities involved may be written as follows:

$$m=\frac{1}{\pi b}\times\frac{L}{R}\times\sigma T^4 \tag{1}$$

Where m is the least mechanical equivalent of light, b is the brightness in candles per square centimeter, R is total radiation, L the luminously evaluated radiation, σ the Stefan-Boltzman constant and T the absolute temperature.

As I have pointed out in a previous paper,[2] the quantity $\frac{L}{R}$, the luminous efficiency, is a function of $\frac{C_2}{T}$ so that the equation may be rewritten:

$$m=\frac{1}{\pi b}\times f\left\{\frac{C_2}{T}\right\}\times\sigma T^4 \tag{2}$$

There are certain advantages in expressing the relationship in this way, prominent among which is the fact that the black body constants, while known to within a comparatively small uncertainty are, nevertheless, not as yet sufficiently certain to make reliable computation of luminous properties possible to the degree of accuracy necessary. Hence, the most that can be done at the present time is to compute the numerical values of the above equation in such form that any chosen values for the black body constants may be inserted, with the prospect of inserting more accurate values as they become determined.

The occasion of the preparation of this note is the recent addition to our fund of necessary data of two fundamental pieces of information. The first of these is an accurate determination of the luminous efficiency curve of the spectrum by Gibson and Tyndall,[3] the second is a determination of the brightness of the black body at the melting point of platinum, by the writer.[4] Assuming these new data as definitely fixed constants in the problem, it is here shown to what values for the least mechanical equivalent of light we are led, upon assuming the most probable values for the black body constants and the melting point of platinum.

[2] "The Photometric Scale"—Ives—Jnl. Franklin Institute, p. 217, August, 1919.

[3] "Visibility of Radiant Energy"—Gibson and Tyndall—Sci. Papers, Bureau of Standards, No. 475; August 1923.

[4] "A Primary Standard of Light Following the Proposal of Wardner and Burgess"—Ives—Jnl. Franklin Institute, p. 147, February, 1924.

The first step is the determination of $\frac{L}{R}$ as a function of $\frac{C_2}{T}$. This has been done in the present case entirely graphically. The entire wave length distribution of emission curves for the black body for values of $\frac{C_2}{T}$ corresponding to the total range of temperatures in which the melting point of platinum must lie (2025 to 2040° K) and the total range of values of C_2 which are at all probable in the light of the most recent work (14200 to 14400) have been computed and drawn. The values of $\frac{C_2}{T}$ thus chosen lie between 6.96 and 7.12. These curves have then been multiplied, wave length by wave length, by the luminous efficiency curve, as determined by Gibson and Tyndall. The resultant values for $\frac{L}{R}$ in terms of $\frac{C_2}{T}$ are plotted in Fig. 1.

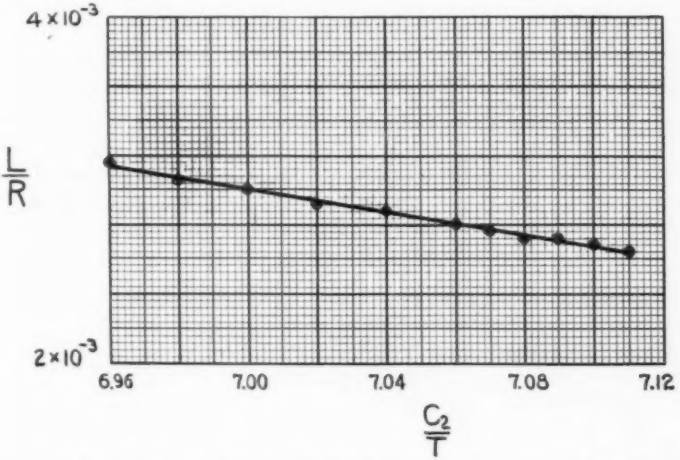

FIG. 1. *Variation of luminous efficiency of black body with C_2/T for range covering melting temperature of platinum and probable values of C_2.*

An interesting fact is brought out on inspection of this plot, namely that *the data are represented accurately by a straight line.* The equation of this straight line proves to be:

$$\frac{L}{R} = \left(26.62 - 3.375\frac{C_2}{T}\right)10^{-3} \qquad (3)$$

Consequently, over the range of values of $\frac{C_2}{T}$, in which we are interested as users of the black body at the melting point of platinum, we have as our equation for the least mechanical equivalent of light—

$$m=\frac{1}{\pi b}\times\sigma T^4\times\left(26.62-3.375\frac{C_2}{T}\right)10^{-3} \qquad (4)$$

This equation incorporates the Planck black body equation and the experimental luminous efficiency curve of Gibson and Tyndall. It is available for use with a wide range of choices of the constants involved in the general equation (1). In order to arrive at a value for m, it is necessary to insert values of b, σ, T and C_2. For b we may insert the recently determined value, namely, 55.4 candle power per sq. cm. T is not at present known accurately, but a probable value is 2035° absolute.[5] For σ and C_2 we may take values computed from recent values for the fundamental constants, h, k and c. Thus, for $h=6.555\times10^{-27}$, $k=1.372\times10^{-16}$, $c=2.9986\times10^{-10}$, we have $\sigma=5.72\times10^{-5}$, $C_2=14330$. On inserting these in the equation, we arrive at the result:

$$m=.00161 \text{ watts per lumen.}$$

It is of interest to compare this figure with that obtained in the earlier investigation quoted, where the monochromatic green mercury radiation was measured. Taking the result then obtained, $.00163\,\frac{\text{watt}}{\text{lumen}}$, and multiplying it by the luminous efficiency of wave-length, $.5461\mu$, as taken from Gibson and Tyndall's curve, namely .985, we get—

$$m=.00160_5\,\frac{\text{watt}}{\text{lumen}}$$

in practically perfect agreement with the value just obtained from the black body measurement.

RESEARCH LABORATORIES OF THE
AMERICAN TELEPHONE AND TELEGRAPH CO., AND
WESTERN ELECTRIC COMPANY, INC., NEW YORK CITY.
JULY 16, 1924

On certain Bands in the Spectrum of a Discharge in Hg Vapor, ascribed to a Mercury Hydride.—These bands, of which the attribution to a mercury hydride is based on the wide spacing of their lines and the absence of isotope effects, are found to be unusually prominent in the spectra of mixtures of Hg vapor and H_2 gas, and to fade out as the H_2 is pumped away. From a quasi-thermodynamical argument as to the abundance of reverse-collisions, Compton concludes that the direct effect of a collision between an excited Hg atom and a H_2 molecule is to produce a molecule of HgH and an atom of H; but an attempt to excite the bands visibly by irradiation of the mixture with 2536 failed. [K. T. Compton and L. A. Turner, Princeton; Phil. Mag. *48*, pp. 360-363, 1924.] K. K. DARROW

[5] Private communication from the Director of the Bureau of Standards.

THE EFFECT OF HEAT TREATMENT UPON THE CATHODO-PHOSPHORESCENCE OF FLUORITE

By Frances G. Wick and Josephine M. Gleason

During a study of the effect of heat treatment upon the cathodo-luminescence spectra of certain fluorites,[1] some changes in the phosphorescence were observed which led to the work described in this paper. The observations here reported were made to determine the way in which the phosphorescence excited by cathode rays is changed by heating the specimens before excitation and include a study of the effect of previous excitation and of variation in the period of bombardment.

Fluorites from different localities differ greatly in color and in period and intensity of phosphorescence. The specimens used for this work were the same as those used for the spectroscopic study and are designated by numbers corresponding to those used in the previous paper[1] for the same specimens. A detailed account is here given of typical results obtained upon the following fluorites in which various rare earth impurities were detected by spectroscopic analysis:

Specimen 1 Blue-green fluorite from Weardale, England.
Specimen 2 Purple fluorite from Weardale, England.
Specimen 3 Yellow fluorite from Scoredale, Westmoreland.
Specimen 5 Chlorophane from Virginia.

Procedure

The method of studying the decay of phosphorescence excited in these specimens by cathode rays is one which has been commonly used. The specimen, placed in a cathode-ray tube in such a position that the rays struck it at an angle of about 45°, was excited by the discharge from a Wappler machine at varying voltages corresponding to an equivalent spark gap of from less than 1 cm to 2 cm. Since the specimens gave off gas upon bombardment, it was necessary to keep the oil pump, which was used for exhausting the tube, running all the time. The arrangement of apparatus used to study the decay is shown in Fig. 1. A Lummer-Brodhun cube A was placed at one end of a track XY, about 3 1/2 meters long, and the specimen in the cathode ray tube, was placed opposite one face of the cube. The comparison source L, a tungsten lamp of low voltage, was mounted on a carriage C, running on the

[1] F. G. Wick, Physical Review, *24*, p. 272; 1924.

track, on which, at intervals of 25 cm, stops were placed. Colored and ground glass absorption plates PP' were inserted to obtain a comparison light of proper color and intensity. A chronograph was used for the measurement of time, starting when the cathode-ray bombardment was stopped by breaking the primary circuit of the transformer of the Wappler machine. The time was again recorded when the intensity of

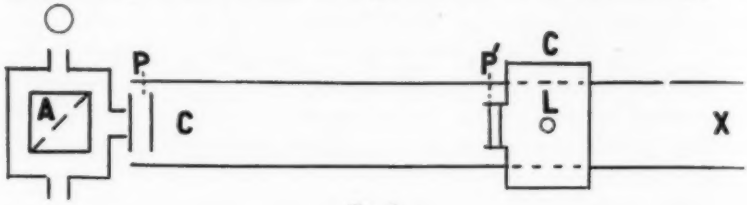

FIG. 1.

the specimen B matched that of the comparison L in its nearest position. The carriage was then moved to the next stop and allowed to remain until a match was obtained, and this procedure was continued until the phosphorescence was too faint to observe.

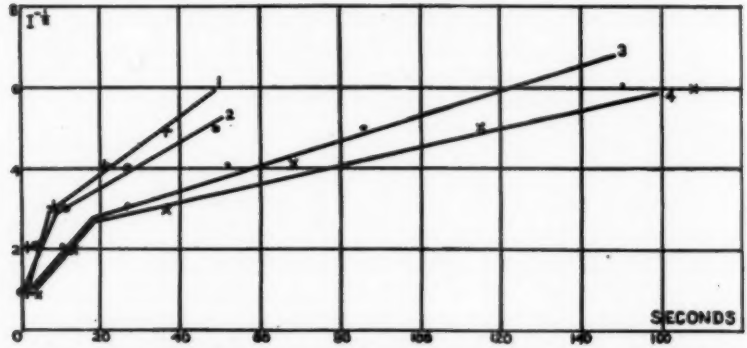

FIG. 2.—*Specimen 2. Decay curves showing effect of heating and repeated exposure to cathode rays.*
Time of exposure for all curves, 15 sec.
1 and 2, unheated specimen; interval, 190 sec.
3 and 4, heated specimen; interval, 370 sec.

After the phosphorescence of the natural material had been observed in this way, curves were obtained from pieces of the same specimens subjected to various forms of heat treatment. The material was placed in a muffle resistance furnace and gradually heated up to temperatures as high as 600°C. In general, the effect of heating was to remove all color from the natural fluorite and to change the color of the cathodo-

luminescence, usually adding to the original green or blue a small component of red. The period of phosphorescence was, for most fluorites, longer after heating, although there were several exceptions to this rule. The effect of repeatedly bombarding the specimens was observed, and a comparison was made of the curves observed with the same specimen following excitations of different lengths.

Fig. 2 shows the results obtained from specimen 2. Curves 1 and 2 are decay curves of the natural crystal taken after two consecutive exposures to cathode rays. Curves 3 and 4 are corresponding curves taken after the specimen had been heated for 2 1/2 hours, reaching a maximum temperature of 400°C.

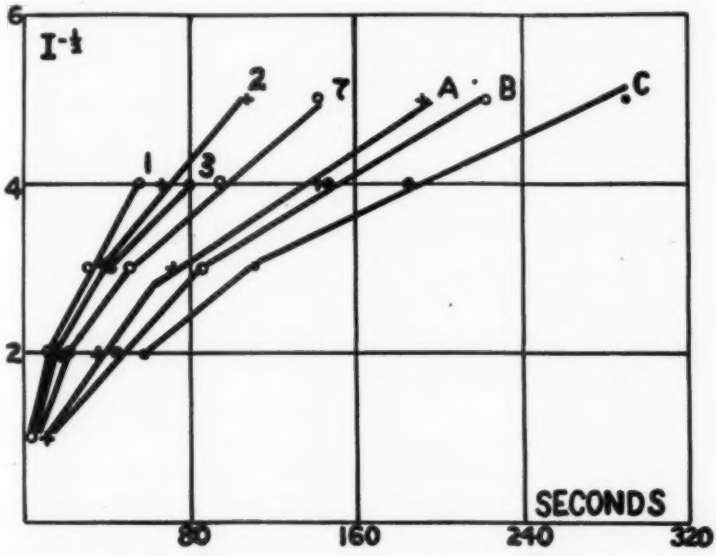

FIG. 3. *Specimen 3. Curves showing effect of repeated exposure.*

1, 2, 3, 7; unheated specimen (curves between 3 and 7 omitted); exposures, 30 sec.; interval between exposures, 150 sec.

A, B, C: specimen previously heated to 400°C for 2 hours; exposures, 15 sec.; intervals 300 sec.

It will be observed that these curves are all of the usual type for long period phosphorescence, consisting of two linear processes, the first of which is the more rapid. A comparison of curves 1 and 2 with 3 and 4 shows that the heating before bombardment increases the duration of phosphorescence and makes the rate of decay slower. Comparison of 1

with 2 and of 3 with 4 shows that the rate of decay is slower after the second bombardment in each case than after the first. This is the effect usually observed in phosphorescent materials, and indicates that there is a building up of the phosphorescence by repetition of excitation, due to some secondary change that persists after the phosphorescence has disappeared.

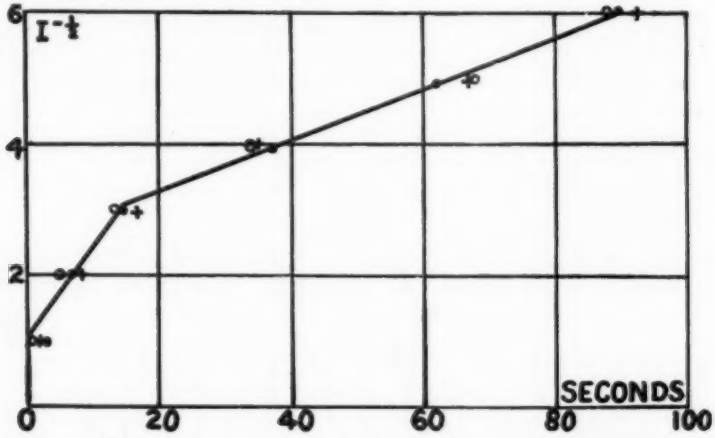

FIG. 4. *Specimen 3. Saturation produced by repeated exposures of 10 seconds each.* Identical curves due to three exposures preceded by others.

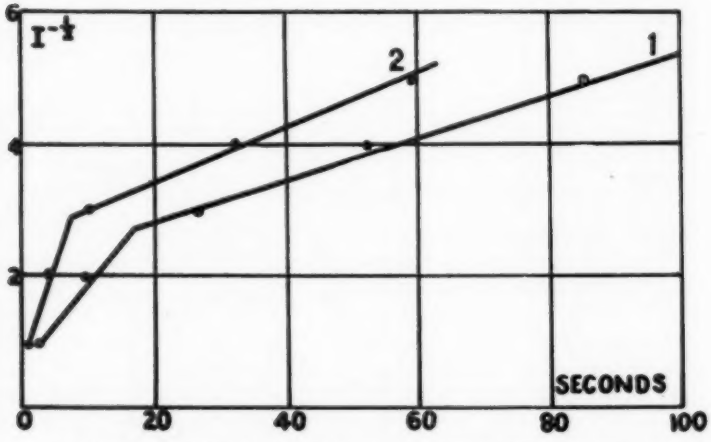

FIG. 5. *Specimen 2. Effect of length of exposure on heated specimen.*
1—exposure 15 sec.
2—exposure 6 sec.

Fig. 3 shows the effect of continued repetition of excitation of natural and heated samples of specimen 3. It will be observed that the duration of phosphorescence in the heated material, curves *A* to *C*, is much greater than in the natural specimen, curves 1 to 7, although the exposure was only half as long. The lengthening of the period upon repeated exposure continues up to a certain point depending upon the

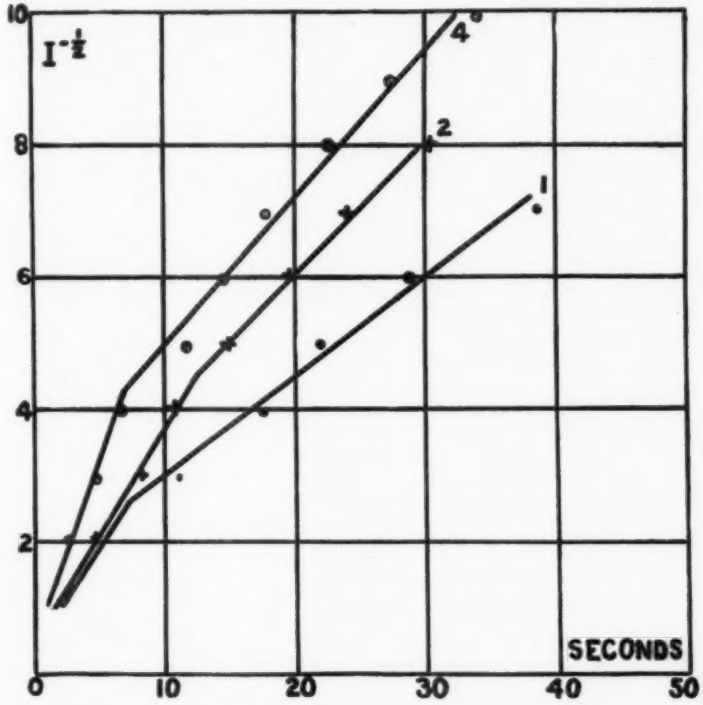

FIG. 6. *Specimen 2, after fusion in oxyhydrogen flame.*
Exposures of 1, 2, and 4 were 5, 10 and 30 sec.
Interval between 1 and 2, 180 sec.; between 2 and 4, 215 sec. An exposure of 12 sec. was made between 2 and 4.

duration of excitation and the interval, then a state of saturation is reached beyond which further exposure produces no change in the curve. Fig. 4 shows such saturation in specimen 5 after a number of exposures of 10 seconds each.

Figure 5 shows the effect produced by varying the period of excitation. The longer exposure was made first and the specimen rested over

night before the shorter exposure was made. As is to be expected, the longer exposure is followed by the longer period of decay.

FUSED SPECIMENS

Specimens of fluorite fused by playing over their surface an oxy-hydrogen flame and subsequently heated in an ordinary blast were found to acquire optical properties radically different from those observed in the unfused state,[2] changes probably due to oxidation of the surface. The phosphorescence color of the material in the oxidized

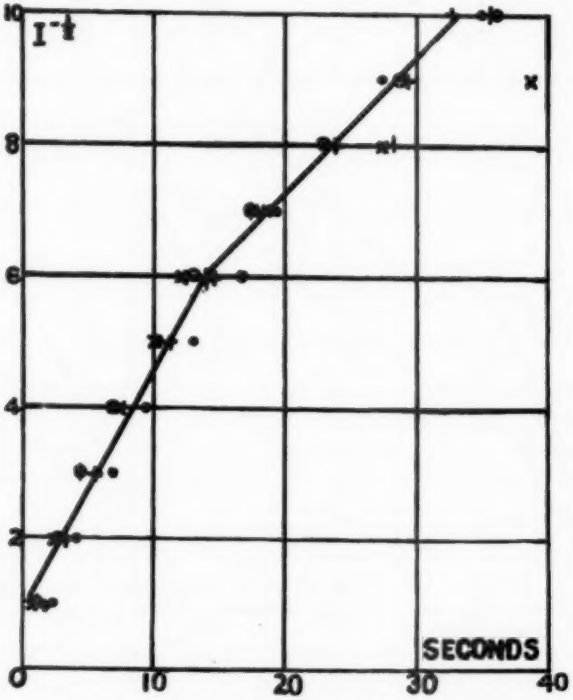

FIG. 7. *Specimen 2, fused, same as for Fig. 6, 10 minutes later.* Exposures of 5, 10, 20, 30, and 50 sec; intervals 106, 100, 102, 112 sec.

state was usually red or yellowish instead of the blue or green of the natural specimens. A study of the phosphorescence of this oxidized material proved to be of special interest because the effect of repeated bombardment was found to be opposite to that observed in natural fluorite and in many other substances.

[2] F. G. Wick, Phys. Rev. *24*, p. 272; 1924.

When a freshly fused sample of specimen 2 was bombarded repeatedly, the period of decay was made shorter by each succeeding excitation, as shown in Fig. 6. Sufficient repetition of bombardment brings about a condition of saturation after which no change is produced by repeated bombardment, as is shown in Fig. 7.

Fig. 8 shows a series of decay curves for the same specimen after it had rested for 24 hours. The effect of repeated excitation is in the same direction as for the freshly fused specimen but less pronounced.

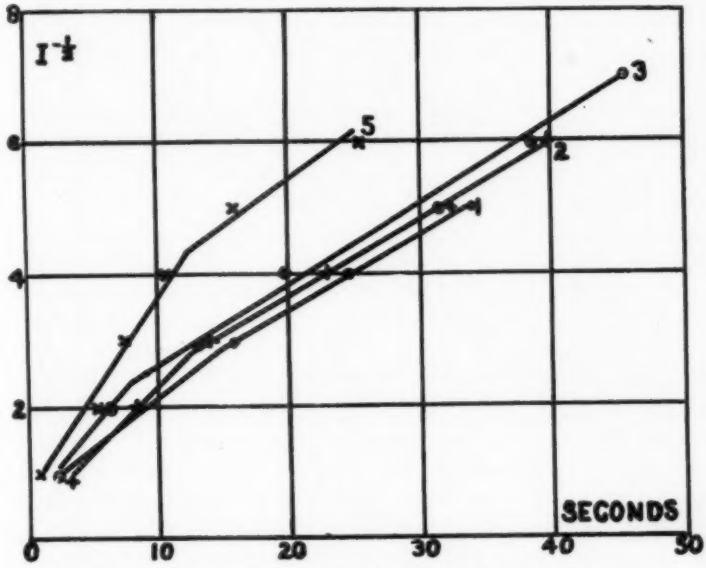

FIG. 8. *Specimen 2, fused; same as for Figs. 6 and 7, 24 hours later.*
Exposures for 1, 2, 3 and 5 were 5, 10, 20, and 60 sec.
Intervals 83, 98, 140 sec.

Many observations made on fused samples of specimen 1 brought out the same points as those observed with specimen 2. A typical set of curves is shown in Fig. 9. It will be observed that the period after the second exposure is slightly longer than that after the first, conforming with results usually obtained, but the period is shortened by subsequent bombardments as in the case of specimen 2. This shortening of period with repeated bombardment was found repeatedly in a number of sets of observations upon both specimen 1 and specimen 2.

DISCUSSION OF RESULTS

The difference in behavior of the natural and fused specimens is very striking in that the period of the one increases under the same treatment which causes that of the other to decrease. One possible explanation is that the fused specimens are very sensitive to temperature changes and become more conducting with the rise in temperature which takes place under cathode bombardment. Natural fluorite,

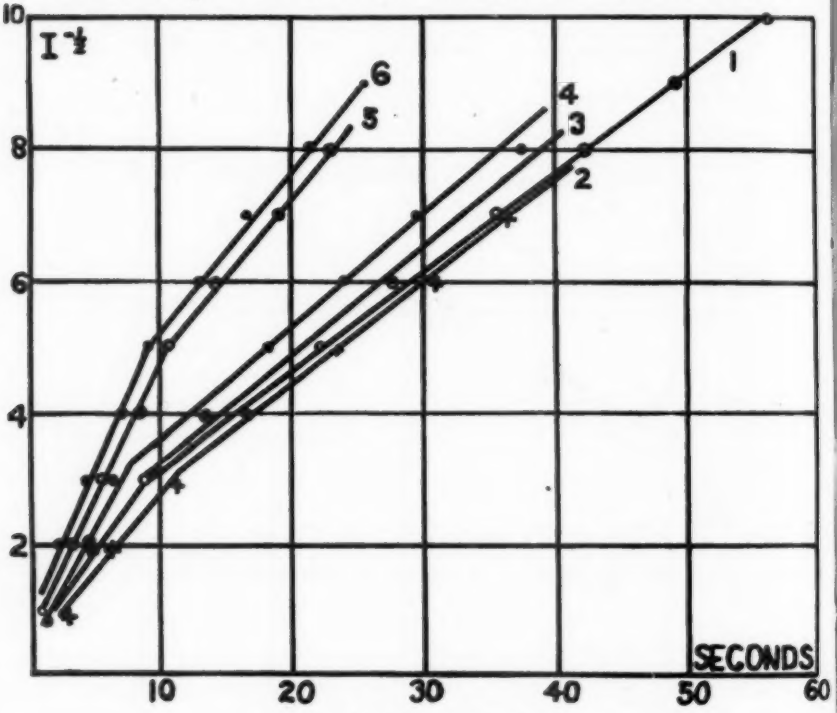

FIG. 9. *Specimen 1, fused.*
Exposures for 1, 2, 3, 4, 5, and 6, were 5, 10, 20, 40, 50 and 60 sec.
Intervals approximately 100 sec.

which shows an increase of period upon repetition of bombardment, is not sensitive to temperature change and the effect of an excitation persists. It is thought that increase in conductivity of phosphorescent material shortens the period of decay by facilitating the return to the normal condition of electrons displaced during excitation. An increase in conductivity of the fused material may shorten the period more than

the stimulus from previous excitations tends to lengthen it. This would explain such results as those shown in Figs. 6, 8, and 9. The lengthening of the period after the second bombardment shown in Fig. 9 may be explained by assuming that the rise in temperature after the first excitation was not sufficient to counteract the persistent effect of the bombardment. After succeeding bombardments the period was reduced by rise in temperature to such an extent that any tendency to increase due to bombardment was counteracted.

It has been observed that clear, perfectly formed crystals have a shorter period of phosphorescence than the more opaque and less perfect specimens. Pulverizing the specimens was observed to increase the period and the process of heating previous to bombardment which lengthens the period usually leaves the specimen cracked and opaque. These effects may also be explained by assuming that the conductivity of the perfect crystals is higher than that of irregular masses.

A possible factor in the explanation of the difference in the response of the fused and the unfused specimens to cathode rays is the fact that the oxidized specimens used were thinner and only the surface is excited to luminescence while, in the case of the natural crystals, the light extends throughout the crystal and can be seen from a side of the specimen not directly bombarded. Since the crystal is not a good conductor of heat, the luminescing material as a whole is probably not at so high a temperature as the surface of the fused specimen. It is possible that this luminescence seen throughout the natural crystal may be the result of secondary radiations such as x-rays or ultraviolet light and the clear crystals are transparent to it.

Another possibility is that a surface film forms over the fused specimen upon bombardment, diminishing the power of succeeding excitations to penetrate to the phosphorescing centers. This, however, seems improbable because the fused specimens change very little in appearance under cathode rays and are relatively permanent compared with natural crystals which, as is well known, discolor very rapidly upon bombardment. Although the period of the fused specimen is shortened by repeated bombardments, it is restored to its longer duration by a time of rest.

The idea also suggests itself that the difference in behavior between the fused and natural specimens may be due to a fundamental difference in the nature of the radiators producing the phosphorescence. In the case of the fused specimens, the phosphorescent light is practically all in the red end of the spectrum due to the line-like bands which are so

conspicuous in this region. In the case of the natural crystals the luminescence comes from broad, diffuse bands. It seems possible that the vibrators producing the very sharp, narrow bands of the fused specimens are atomic. As has been previously suggested they may be rare earth atoms which have taken the place of other atoms in the regular crystal lattice of calcium oxide, the limitations imposed by this lattice accounting for the sharp lines in the luminescence spectra. The vibrators producing the banded spectra of the natural fluorites may be molecular in nature. The difference in the effect of cathode-ray bombardment upon two such different sources of emission may account for the observed differences in the effect of repeated bombardment upon the period of phosphorescence.

It is a pleasure to acknowledge assistance in this work from the Rumford Fund of the American Academy of Arts and Sciences and from the Ellen Richards Grant of the Association to Aid Scientific Research by Women.

VASSAR COLLEGE,
POUGHKEEPSIE, NEW YORK.

Correlation between Cathode Fall and Thermionic Work Function.—Evidence for such a correlation has been sought for a long time in spite of the fact that the cathode-fall is a function not of the cathode metal but of the gas sustaining the discharge as well. Günther-Schulze assembles measurements of cathode fall (from three sources) bearing on some nine elements (metal and carbon) in each of seven gases; some new measurements in hydrogen are incidentally published. Dividing all these data by the values of thermionic work function (taken from Langmuir) for the corresponding metals, quotients are obtained which for individual gases are more or less constant; e. g. they range from 37.1 to 51.0 for Ne, from 34.6 to 48.3 for one set of data on Ne, from 37.6 to 47.2 for another set on Ne, etc. Whether this material is sufficient to prove more than a general tendency of higher values of work-function to go with higher values of cathode fall must be left for each reader to judge from the tables and the graph. The same must be said for the values of the ratio (work function)/(cathode fall) given as characteristics of the various gases, and the estimates of work function for various elements as yet not subjected to thermionic experiments. [A. Günther-Schulze, Reichsanstalt; ZS. f. Phys. *24*, pp. 52-55, 1924.]

K. K. DARROW

DIFFRACTION AT A NARROW SLIT[1]

By Robert L. Turner

In 1819 Fresnel[2] gave an explanation of the rectilinear propagation of light on the wave theory proposed and championed by Huygens. By making use of Huygen's principle and the principle of interference, he was able to derive mathematical equations giving the distribution of illumination in simple cases of diffraction. For diffraction of cylindrical wave-fronts at a narrow slit he showed that

$$I = K\left\{\left[\int_{-v_0}^{v_1}\cos\frac{\pi}{2}v^2dv\right]^2+\left[\int_{-v_0}^{v_1}\sin\frac{\pi}{2}v^2dv\right]^2\right\} \tag{1}$$

where I is the intensity on a screen, mn, (Fig. 1) parallel to the plane of the slit, at a point, P, a distance, x, from M, the foot of the perpendicular from the line source of illumination, A, to the screen. K is a

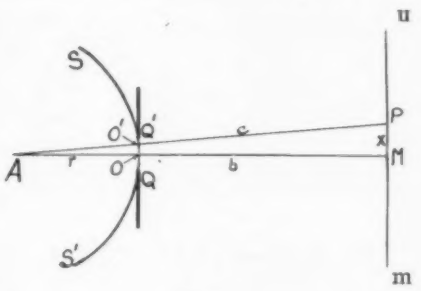

Fig. 1

factor of proportionality, and v is a variable depending on the wavelength, c, and s, the distance measured along the arc of the wave-front from O' in the direction $O'S$. The exact value of v is given by the relation

$$s = \sqrt{\frac{c\lambda}{2}}\,v \tag{2}$$

Since P is any point on the screen, the intensity may be found for all points when s, c, and λ, are known; and curves may be drawn showing

[1] Abstract of thesis offered in partial satisfaction of requirements for master's degree at the University of California.

[2] Crew, Wave Theory of Light.

the distribution of illumination along the screen. Such curves are more easily drawn, however, by use of the Cornu spiral.[3] This spiral, Fig. 2, is the graph of the equations

$$x=\int_0^v \cos\frac{\pi}{2}v^2dv \qquad y=\int_0^v \sin\frac{\pi}{2}v^2dv$$

It can be shown that the square of the chord T_1T_0, between the points T_1 and T_0 which mark distances v_1 and $-v_0$ from the origin of the spiral is the expression in the braces in equation (1) above. The location of T_1 and T_0 corresponding with a given point, P, on the screen may be determined as follows:

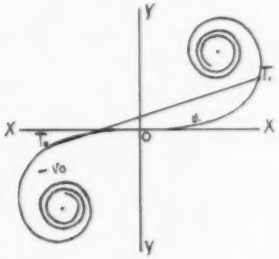

FIG. 2

When P falls on M, $OQ'=O'Q'$; and hence $v_1=-v_0$. If P be shifted a distance, x, from M; O' is shifted a distance OO' from O. For small values of x, OO' is proportional to x; and since, from (2), OO' is proportional to the corresponding change in v_1; it follows that the shift in T_1 along the spiral is proportional to x. Also, for a given width of the slit, the arc of the spiral is constant; and, therefore, T_0 must be shifted as many units as T_1 and in the same direction. When P falls on M, T_1 and T_0 mark off distances v_1 and $-v_0$ such that $v_1=-v_0$ and the arc T_1T_0 is given by the relation $T_1T_0=QQ'/\sqrt{\frac{c\lambda}{2}}v$. The curves, then, are drawn by laying off distances on the screen from M as abscissae, and plotting as ordinates corresponding to points, P, on the screen, the square of the chord T_1T_0 when T_1 and T_0 have been shifted as many units along the spiral from the central position as P is taken units from M.

Curves drawn by the method just described show a general maximum of illumination in the neighborhood of M, superposed upon which

[3] Journal de Physique, *3*, 1874.

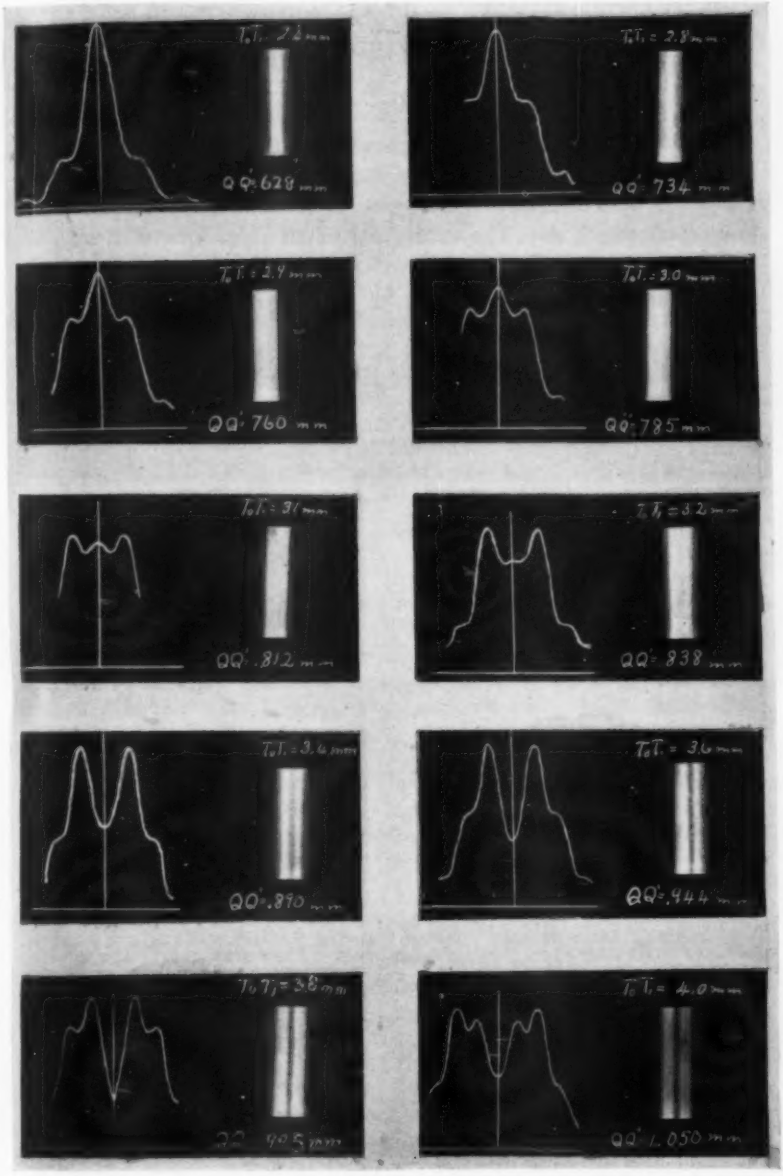
T₀T₁ = 2.2 mm
QQ' = 628 mm
T₀T₁ = 2.8 mm
QQ' = 734 mm
T₀T₁ = 2.9 mm
QQ' = 760 mm
T₀T₁ = 3.0 mm
QQ' = 785 mm
T₀T₁ = 3.1 mm
QQ' = 812 mm
T₀T₁ = 3.2 mm
QQ' = 838 mm
T₀T₁ = 3.4 mm
QQ' = 890 mm
T₀T₁ = 3.6 mm
QQ' = 944 mm
T₀T₁ = 3.8 mm
QQ' = 995 mm
T₀T₁ = 4.0 mm
QQ' = 1050 mm

FIG. 3. *Diffraction at a narrow slit.*

there may occur secondary maxima and minima depending on the length of the arc of the spiral chosen for plotting the curves. Fig. 3 shows a series of such curves. The length of the arc used in their construction was increased in the order in which the curves are arranged. Accompanying each curve is a photograph of the central maximum of the diffraction pattern produced by a narrow slit whose width QQ' was adjusted to the theoretical value demanded by equation (2) on page 649. The diffraction pattern was formed directly on the film from which the pictures were printed.

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Contribution to the Study of the Photoelectric Effect.—Most of this work is done by irradiating one side of a metal sheet, the other side of which is functioning as an electrode in an electrolytic process, so that gas (hydrogen or oxygen) is being developed there. Confirming earlier results it is found that the effect of the electrolysis is invariably to increase the photoelectric sensitiveness of the metal sheet (iron or palladium; irradiation by unresolved light of the mercury arc through quartz); the increase is considerable, sometimes to several fold the initial value; but it is very transient, the current tumbling down again in the few minutes after the electrolysis ceases. The same sort of thing occurs when hydrogen is evolved on the far side of the plate by attacking it with sulphuric acid. It occurs whether the irradiated surface is fatigued by long exposure to light, or is freshly exposed by shaving just before or just after the electrolysis. With copper, which is said not to absorb gases beyond a negligible amount, there was only a minute effect, attributed to secondary causes. The suddenness of the changes, in the case of iron, is said to invalidate the idea that the temperature changes of the metal are responsible for them. However, the authors made direct observations on the effect of temperature change in the hope of observing the curious effect lately reported by Shenstone (Phil. Mag. *45*, pp. 918-926; 1923). A sheet of copper (.05 mm thick?) heated through 15° (the temperatures were measured by a thermocouple pressed against the edge of the sheet) by a current through it, exhibited an increase of 2.15 per cent in sensitiveness, but when heated through 18° by a current in a coil just behind it there was an increase of 3.20 per cent. Analogous results were evidently obtained with iron but the account is not clear; it is stated, however, that when the temperature rise was kept down to 1.5° by watercooling applied to the far side of the sheet, the increase in sensitiveness was only some 1 per cent. (The photoelectric currents were measured while the heating-current was interrupted, to avoid difficulties with the magnetic field). The problem, therefore, remains obscure. [R. Dümpelmann and W. Hein, Münster; ZS. f. Physik, *22*, pp. 368-373, 1924.]

K. K. DARROW

INSTRUMENT SECTION

OIL IMMERSED X-RAY GENERATING OUTFITS AND THEIR USES

By W. D. Coolidge

The application of x-rays has almost invariably been attended by the possibility of accidental electric shock to the operator and, in medical applications, to the patient as well. In the early history of the art, when the x-ray tube was excited from a static machine, an induction coil or a high-frequency coil, contact with the high tension circuit ordinarily involved only annoyance and discomfort. With the advent of higher power tubes, operated from transformers, that which had been merely a possible source of annoyance became a real danger. The hazard was still further increased when, for radiographic work, the rheostat in the low tension circuit, used to control the voltage in the high tension circuit, was replaced by an auto-transformer.

The electrical danger could, at any time, have been eliminated by putting the whole high tension system, including the x-ray tube, into an earthed metallic enclosure. This method, however, when applied to the early forms of x-ray apparatus would, in general, have rendered them bulky and, mechanically, relatively inflexible.

With the advent of a self-rectifying x-ray tube, which is stable and can be made very small, it became interesting to mount the x-ray tube inside of the transformer tank and in the same oil with the transformer, making the latter as small as possible. In another paper[1] the writer has described his earlier work in this field. The following is a description of two experimental outfits of the oil-immersed type, which have been more recently developed. They were both intended primarily for medical diagnostic work. Laboratory experience with these outfits shows that they should also have many other fields of usefulness. They lend themselves especially well to physical demonstrations and, in general, to cases where x-rays are desired for short periods of time.

Owing to the enclosure of the whole high tension system in a grounded metal container, there is, with this system, no external electrostatic field. This eliminates the danger of electric shock and is an advantage

[1] Am. Jour. of Roentgenology, 7, pp. 181-189, 1920.

in some experimental work where the effect of x-rays might otherwise be masked by the presence of the electrostatic field of the high tension system. This type of apparatus also permits a very close approach to the focal spot and, hence, to a region of strong x-ray intensity. Other advantages are to be found in the mechanical ruggedness of the apparatus and in the simplicity of its operation.

DENTAL OUTFIT

The small outfit described in this section was developed primarily for the use of the dentist for intraoral radiography.

In its mechanical design the aim has been to attain the following ends:

(1) To enable the operator to follow his visual inspections by a radiograph without having to, in any way, change the position of the patient.
(2) Easy and smooth mechanical operation of the outfit.
(3) Easy and complete removal of the outfit, when not in use, from the neighborhood of the patient.
(4) The occupation of as little floor space as possible.

On the electrical side, attention has been given to:

(1) Electrical protection from both the high tension and low tension circuits.
(2) Minimizing the effect of line voltage fluctuations by the use of a stabilizer which holds milliamperage constant.

The attractiveness of the system is very largely dependent upon the degree of perfection attained in the mechanical and electrical design. This is due mainly to the following considerations:

To move the source of rays, it is necessary with this system to move the whole x-ray generating outfit, which is, of course, heavier than a simple x-ray tube and protective shield. To make such movement easy and smooth, and this is very desirable for work about the face, friction must be reduced to a minimum. To this end, the weight of the generating outfit must be reduced to a minimum. Light weight is desirable for two other reasons. Even if there were no friction, there is the inertia of the mass to be overcome in putting the outfit in motion or in stopping it. Furthermore the weight has to be carried, in some positions, at a distance of several feet from the supporting wall or column and this calls for a very strong support, unless the weight is kept small.

Because of the diminished accessibility of its parts, such an outfit, to be desirable, must operate faultlessly for long periods of time.

GENERAL DESCRIPTION

The dental outfit is shown in Fig. 1 and consists of an x-ray generating unit which is completely enclosed in the grounded metallic container, *M*, and is mounted on pivots in a rotatable fork, *F*, attached to a special wall bracket. This mounting permits the unit to be pointed in any direction, raised and lowered and brought to any point within quite a large space. Through accurate balancing of parts and the use of friction devices, the movement of the unit is made easy and smooth

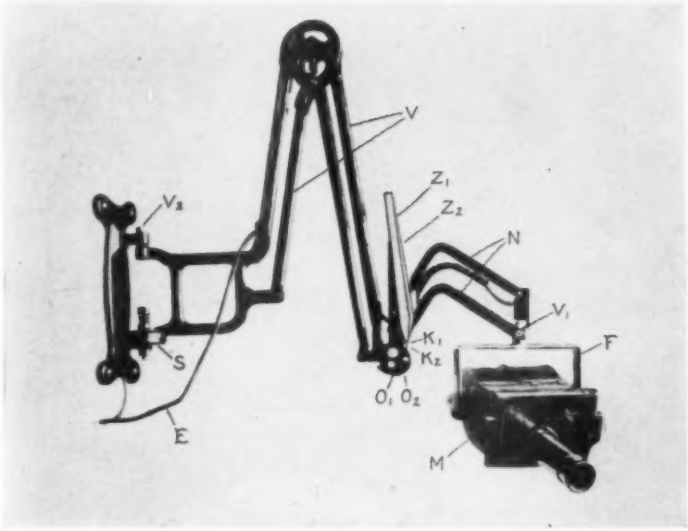

FIG. 1. *Dental unit mounted on wall bracket.*

and it stays wherever it is put without the use of clamping devices. Low tension is led to the transformer by means of the single conductor insulated cable *E* passing through metal conduits. The grounded metal bracket itself is used for the return circuit. At no point is the live side of even the low tension circuit exposed. The x-ray tube operates at 10 milliamperes and 56000 volts (max.), and the time factor is automatically controlled by means of a small time-switch, not shown in the figure.

THE X-RAY GENERATING UNIT

The x-ray generating unit is shown in length section in Fig. 2 and in end section in Fig. 3.

The small x-ray tube, X, is seen mounted close to the high tension coils C_1 and C_2 of the 56000 volt (max.) transformer. The low tension coil, not shown, is on the same leg of the magnetic circuit as the high-tension coils and is inside of the latter. T is the separate filament transformer, M the metal tank and B the Bakelite cover. B_1 is a false cover of aluminum which supports the Bakelite cylindrical tubes

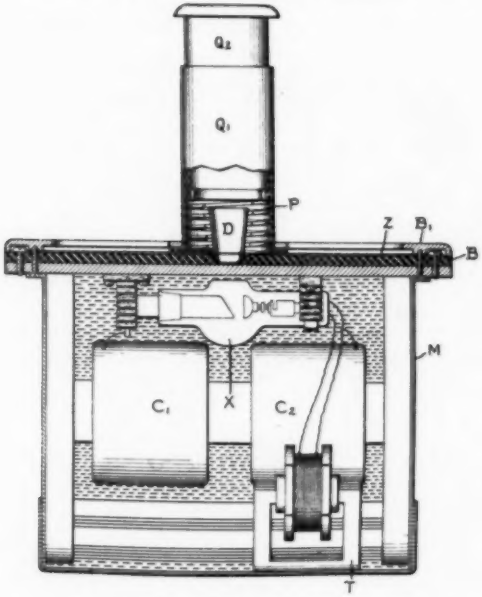

FIG. 2. *Length section of dental unit.*

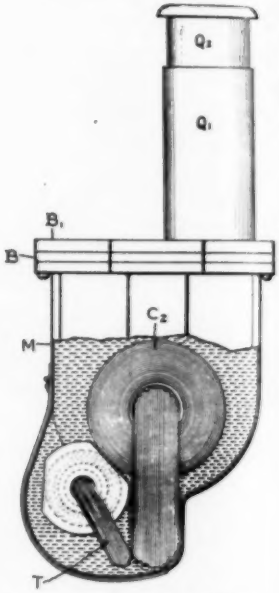

FIG. 3. *End section of dental unit.*

Q_1 and Q_2 which serve to establish mechanical contact with the patient. Z is a sheet of 1/32 inch lead and D is a tapering tube of the same material for the x-ray protection of the operator.

Fig. 4 is a length view showing a cross section of the oil expansion chamber G and the Kearsley Stabilizer J together with the resistance unit R, which is automatically cut in and out of the filament circuit by the stabilizer. W is a cover, here shown raised, but ordinarily closed, to protect the stabilizer and resistance unit.

THE SUPPORT MECHANISM

The x-ray unit, which weighs 20 pounds, is rotatably so mounted in a steel fork that the axis of rotation passes through the center of gravity

of the unit. The fork is itself rotatable about its vertical axis, V_1, Fig. 1. A link mechanism, N, permits of raising or lowering the unit through a distance of 14 inches. Freedom of motion in an essentially horizontal plane is permitted by an S. S. White dental bracket, V, (here used in an inverted position). The whole supporting arm is made rotatable about a vertical axis, V_2.

So far as its vertical motion is concerned, the weight of the unit is accurately balanced in all positions by a pair of spiral springs (inside of the tubular spring-housings), Z_1 and Z_2 and steel cables, K_1 and K_2, passing over specially designed cams, O_1 and O_2. For the purpose of

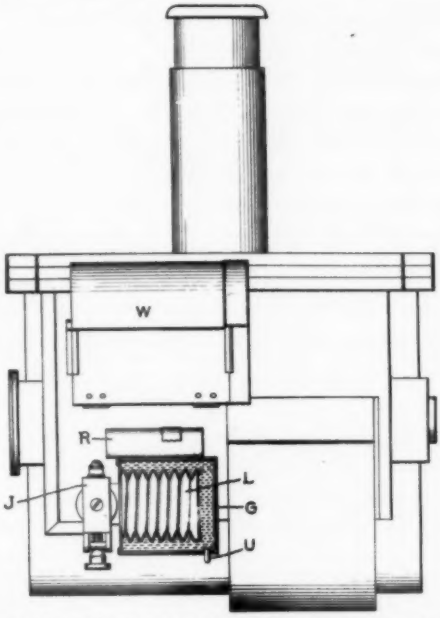

FIG. 4. *Length view of dental unit, with oil expansion chamber, G, stabilizer, J, and resistance, R, uncovered.*

maintaining this balance in the face of changes which may take place in the springs, the tension of the latter is made adjustable.

The design of the dental arm is such that the 20 pound unit is nearly in equilibrium in the horizontal plane.

Through the inherent friction and through the use of friction discs the unit will stay wherever it is put in space.

The bracket may be carried from the wall, as in Fig. 1, from a special column, or from some existing dental fixture.

Relative immobility of x-ray tube and patient is secured by the following artifice: A cylindrical tube of Bakelite or other material, Q_1, Fig. 2, is rigidly attached to the cover of the x-ray unit. A second tube, Q_2, with an easy sliding fit inside the first one and with a travel of about 1 inch, is urged outward by a weak spiral spring, P. The inner tube, moving freely in its sheath, maintains mechanical contact between the x-ray outfit and the patient. The spring under the moveable tube controls the contact pressure and must not be too strong as otherwise it will cause discomfort to the patient. On the other hand, it must not be too weak as otherwise it will not be sufficiently effective. The effect of the contact tube is to hinder relative motion of x-ray outfit and patient in any other direction than the one which is least harmful to the resulting radiograph. Even in this direction also it is quite effective owing to the friction between tube and sheath.

The spring behind the contact tube tends to push the x-ray outfit away from the patient. Such motion, if allowed to take place, would defeat the purpose of the contact tube, and is prevented by the use of a friction device, S, in Fig. 1.

THE X-RAY TRANSFORMER

The small x-ray transformer is the result of a good deal of experimental work. The following are some of the considerations affecting its deisgn.

The smaller the cross-section of the iron core, the greater is the number of turns required in the primary and secondary coils. Reduction of iron beyond a certain point will then lead to an increase rather than a decrease in the diameter of the high voltage coils. Furthermore the effect of the increase in the number of turns will be to increase the resistance of the coils and this, for use on a self-rectifying tube, will, for a given "useful" voltage, increase the "inverse." It will be the higher of the two voltages, the inverse, which will determine the insulation required for the high voltage coils. The increased "inverse" will then necessitate larger secondary coils with more spacing between them and a larger container.

A reduction in the diameter of the copper wire used in the coils will increase resistance and hence increase "inverse." Beyond a certain point, then, a decrease in the diameter of wire will be attended by an increase in the size of the container.

There will be a compromise design which will lead to the smallest and lightest weight outfit.

THE TUBE

Fig. 5 gives a full sized view of the tube and Fig. 6 an enlarged cross-sectional view of the cathode. With the small focusing device, the focal spot would be too small were it not for the molybdenum pin which projects through the center of the filament spiral.

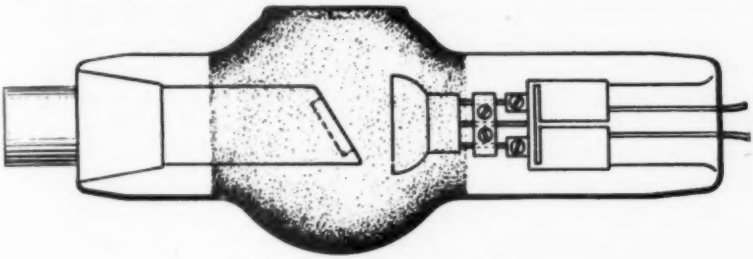

Fig. 5. *Dental tube, full size.*

The tube operates, in oil, at 56000 volts (max.) and 10 ma. The bulb of this tube, the stippled portion in Fig. 5, is made of glass containing 55 per cent by weight of the element lead. The wall-thickness is 1/8 inch. The protection offered by the lead glass envelope is equal to that

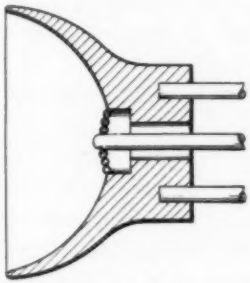

Fig. 6. *Enlarged cross section of cathode of dental tube.*

of 1/32 inch of sheet lead. The window through which the x-rays emerge is made of thin walled, lead-free, lime glass. The focal spot is 1/8 inch in diameter. The angle of the toe of the target has, in this tube, been made 60° instead of the usual 45°, for the following reason: If, through overload or any other cause, the tube should allow any "inverse" current to pass, it is desirable that this "inverse," which

comes from the focal spot in a direction normal to the working face of the target, should be intercepted by the molybdenum focusing device. It would otherwise impinge upon the glass wall of the tube and probably crack this by local heating. The use of the larger target angle brings the normal to the target face nearer to the tube axis and hence permits of the use of a smaller focusing device than would otherwise be necessary and this is important in this case where it is so desirable to make the tube small.

The cathode filament spiral calls for a heating current of 2.2 amps at 2.6 volts. The low filament wattage involved permits of the use of a very small filament transformer.

OIL EXPANSION CHAMBER

As a result of the low efficiency of x-ray production and the location of the x-ray tube in the oil with the transformer, all but a negligible amount (less than one tenth of one per cent) of the electrical energy delivered to the transformer appears finally in the oil as heat.

The tank and other metal parts expand relatively little but the oil expands strongly on heating.

For the device to be operable in all positions, it is necessary, for the insulation of the high tension system, that the tank shall at all times be full of oil.

As the tank is made of thin metal and as it must be maintained perfectly oil-tight, it is not permissible for the oil-pressure within the tank to rise to more than 5 or 10 pounds above that of the atmosphere.

In the present outfit, the expanding oil flows out from the tank through the tube *U* (Fig. 4) into the cylindrical chamber *G*, in which there is an accordion-shaped metal tube, *L*, (a piece of "Sylphon" tubing), closed at the inner (right hand) end, which collapses as oil flows into the expansion chamber.

The advantages in this type of expansion chamber over that formerly used[2] are that it reduces the bulk of the apparatus and reduces the pressure within the tank.

THE STABILIZER

A small Kearsley stabilizer,[3] *J*, Fig. 4, mounted on the outside of the unit, serves to hold the milliamperage constant at the pre-determined value. The mode of operation of the stabilizer is seen by referring to the diagram, Fig. 7. The high tension current which passes through the

[2] Am. Journ. of Roentgenology 7, No. 4, pp. 181-189, April 1920.
[3] W. J. Kearsley Jr., Journ. of Radiology, pp. 3-7, July, 1921.

x-ray tube is made to pass through the magnet coil, H, of the stabilizer. The magnet coil operates an armature, I, which carries one of a pair of co-operating contacts, D_1 and D_2. Through the operation of the stabilizer, the resistance, R, is cut in and out of the primary circuit of the filament transformer. By automatically controlling the fraction of the time that this resistance is in the filament supply circuit, the stabilizer maintains, in spite of line voltage changes and in spite of changes which may take place within the x-ray tube, a constant current through the latter. Owing to the fact that the energy required in the filament heating circuit is so small, only about 6 watts, the sparking at the stabilizer contacts is very slight, a fact which makes it possible to operate the outfit a great many times before it becomes necessary to change the adjustment of the stabilizer.

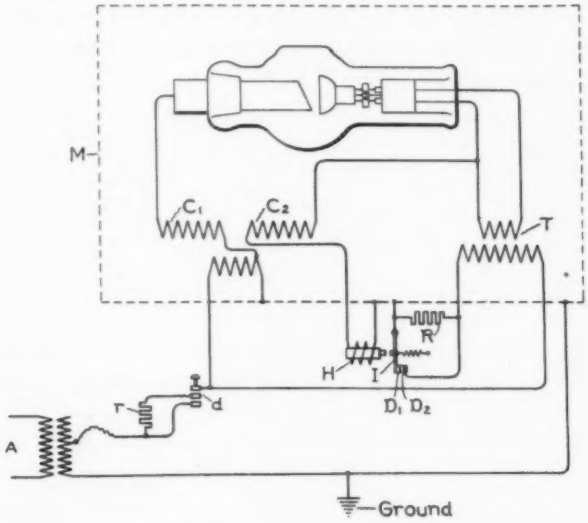

FIG. 7. *Diagram of connections.*

X-RAY PROTECTION

As has been pointed out, the lead-glass wall of the x-ray tube is equivalent in protecting power to 1/32 inch of sheet lead. Further protection might be unnecessary were it not for the following fact: The inner walls of the tube are so close to the focal spot and, hence, exposed to such a high x-ray intensity that they serve as a very strong source of secondary rays and these escape under a wide angle through

the transparent window. To suppress them, a sheet of lead 1/32 inch thick, Z, in Fig. 2, and the lead cone, D, are used.

THE LOW TENSION CIRCUIT

Only one wire is used for the low tension circuit, the supporting arm itself serving as the return conductor. With this system, but two sliding contacts are required, one at the upper end of the fork which supports the unit and the other at one of the lower ends of the fork.

The circuit diagram is given in Fig. 7, in which the letters have the same significance as in the preceding figures.

Current is supplied to the unit from a 1 to 1 transformer, A, provided with several taps. The coil of this transformer which delivers current to the x-ray transformer has one end connected to earth and to the metal support arm and the other end to the insulated cable. The function of this auxiliary transformer is two-fold. Its use makes it safe to apply the ground as shown, and, through the choice of the proper tap, it adapts the line voltage to the unit.

THE OPERATING SWITCH

The operating switch, d, (Fig. 7) first closes the low tension circuit through the resistance, r, and upon being depressed further short circuits this resistance. The use of the resistance point in the switch presents the high voltage surge which would otherwise take place whenever the circuit is closed on the peak of a wave.

ELECTRICAL CHARACTERISTICS

The electrical characteristics, of one of the units, are given in Table 1, in which the first and second columns give the primary voltage and

TABLE 1.

Prim. Volts	Prim. Amps.	Tube Current (Milli-amperes)	Kilovolts (Max.)	
			Useful	Inverse
104.0	4.7	—	——	56.0
86.5	8.5	10	42.0	48.3
92.0	8.7	10	45.5	51.8
97.5	9.2	10	48.3	54.6
103.0	9.7	10	52.5	57.5
105.0	10.0	10	54.7	58.8
109.0	10.7	10	56.0	60.2
114.5	12.3	10	58.9	63.1
119.5	14.3	10	61.6	66.5

current respectively, delivered to the x-ray transformer from an auto-transformer with variable taps. The third column gives the milliamperage flowing through the tube. The fourth and fifth columns give the peak voltage, "useful" and "inverse" respectively, determined by the use of a sphere-gap and kenotron. The normal operating "useful" voltage for this outfit is 56 kilovolts, at which point the "inverse" voltage is seen to be only 7.5% higher than the "useful."

To operate from a direct-current supply, a rotary converter has to be used, and care has to be taken in its design to prevent its causing too large an increase in the "inverse" high tension voltage.

The filament heating current is 2.2 amperes at 2.6 volts.

CAPABILITIES AND LIMITATIONS OF THE SMALL UNIT

To study the effect of mechanical vibration, one of the little units was placed in a close-fitting wooden box and carried about on the floor of an automobile for several weeks of rough winter driving. The mileage involved was small, but twice a day the outfit was taken from the car to the house or laboratory and was, on each occasion, dropped from some little height to the floor. The wiring in this particular outfit had been so arranged that a milliamperemeter could be connected in, and at least once a day the milliamperage was measured. Although the abuse seemed as bad as the wooden box would stand, no damage was done to the unit and the adjustment of the stabilizer remained unchanged, as was shown by the fact that the milliamperage remained constant.

This little unit was intended for diagnostic work only. Even in this field, however, there is a perfectly definite limit to what can be done with it as it stands.

In one experiment, a current of 10 ma at 62000 volts (max.) was thrown on for 5-second periods with 20-second intervals of rest. At the end of 45 minutes the temperature of the oil in the can had risen to 62° Centigrade and the pressure, shown by an attached gage, had risen from 0 to 10 pounds, above that of the atmosphere. While it would not have been safe to go much higher with either the temperature or pressure, no harm had been done to the outfit. This service was equivalent to making 108 intraoral dental radiographs in 45 minutes on slow film. It would not have been safe to continue at this rate as temperature equilibrium had not been reached.

Other experiments indicate that it would be conservative to use the unit continuously for 40 such dental radiographs per hour on "slow"

film or about 200 per hour on "fast" film. This latter figure is probably a higher speed than could be maintained by any operator.

That the life of such an outfit, working within its limitations, should be very long was indicated by an experiment in which an outfit was operated from a motor-driven switch, at 10 ma and 56000 volts, on a schedule of 5 seconds on and 65 seconds off, 109000 times. There was no evidence of the tube having been changed in any way by the experiment.

Six of these experimental outfits have now been in use in dental offices for over two years and during this time only one tube has made trouble.

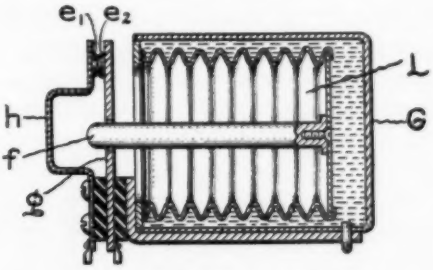

FIG. 8. *Safety device for dental unit.*

Where it is desirable to use the outfit for such hard service that it might otherwise become overheated, the safety device shown in Fig. 8 can be added. The oil expansion chamber, G, is that of Fig. 4 and the safety device consists of a pair of contacts e_1 and e_2 in series with the low tension circuit of the x-ray transformer. As the outfit heats up, oil flows into the chamber G compressing the sylphon, L. The closed end of the sylphon carries a bakelite rod, f, which passes loosely through the contact-carrying member g. When the maximum allowable temperature has been reached, the rod, f, presses against the other contact carrying member, h, and so opens the primary circuit of the x-ray transformer, keeping it open until the temperature of the outfit has fallen to a point where it can be again operated with safety.

If, for any purpose, the outfit is generally to be used in such a position that the tube stands uppermost in the tank above the transformer, the energy which can be continuously dissipated from the tank can be considerably increased by making the tank of copper or aluminum, instead of iron, and making it thick enough so that it will have an essentially uniform temperature throughout. If, on the other hand,

the tank is made of thin sheet iron, then only the oil in the neighborhood of the anode and above it will be hot and, because of this fact and the low heat conductivity of the thin iron, only the upper portion of the tank will be very effective as a heat radiator.

OTHER APPLICATIONS OF THE OIL-IMMERSED DENTAL UNIT

As A Portable Device

In its simplest and most portable form, the unit is shown in Fig. 9, mounted in a wooden box which is provided with a removable cover which carries a suitable handle.

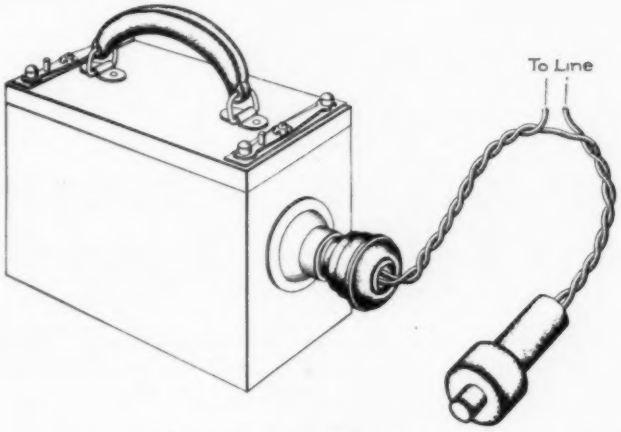

Fig. 9. *Dental unit in portable form.*

The small resistance unit, *r*, of Fig. 7, is included in the handle of the push-button switch.

In this form the unit can be used for bedside radiography.

It seems especially well adapted to use in the surgical operating room for fluoroscopic control in connection with the removal of kidney stones, that is, in those cases where the kidney is, for this purpose, delivered through the wound.

Such an outfit might render useful service to the building-contractor for the floroscopic examination of walls and ceilings for getting information concerning the location of concealed timbers, wires, pipes, etc.

In this form the unit should find many uses in industrial research where it can be employed for easy radiographic or fluoroscopic work, to differentiate between substances which do and those which do not

fluoresce under the influence of x-rays, to ionize gases, to dissipate electric charges on the surface of non-conductors, or with the help of an electric field to give to the surface of either a conductor or an insulator an electric charge of either sign.

For Physical Demonstrations

The following illustrations will serve to show the usefulness of the device in physical demonstrations.

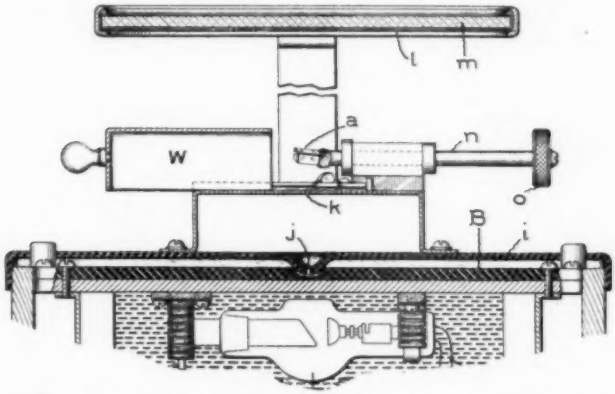

FIG. 10. *Vertical section of unit equipped for fluoroscopic demonstration of Laue diffraction experiment.*

Diffraction of X-rays

With the device arranged as in Figs. 10 and 11, the Laue experiment can be shown fluoroscopically. For this set-up, the cover of the outfit, shown in Fig. 9, has been replaced by a metal plate, *i*, in the small depressed portion of which is an opening, *j*, 0.067″ in diameter. This diaphragm, together with a second one, *k*, having an opening of the same size and mounted $1\frac{3}{8}$″ above the first, serves to define a small beam of x-rays which passes upward to the fluorescent screen,[4] *l*. The observer is protected by the lead glass, *m*.

With the apparatus as shown, a rock-salt crystal, *a*, cemented to the end of a rotatable shaft, *n*, is in the path of the x-ray beam. As the rock-salt crystal is rotated (by means of the knurled head, *o*) the diffraction pattern, seen on the fluorescent screen, shifts, while the primary beam remains fixed in position.

[4] The most sensitive fluorescent screen available should be used for this purpose. That made by the Patterson Screen Company, of Towanda, Pa., has been found very satisfactory

The plate on which the rotatable rock-salt crystal is mounted is pivoted on a vertical axis, *P*, and carries two other crystal fragments, one of sapphire at *q* and one of diamond at *s*. The dotted position shows the crystal *s* in the path of the x-rays, and a position intermediate between the solid and dotted positions brings the crystal *q* into the beam.

Through the agency of a spring actuated pawl, *t*, and two stops, *u* and *v*, the crystal carrying member is given four definite positions, one for each of the three crystals and one in which there is nothing interposed in the path of the rays.

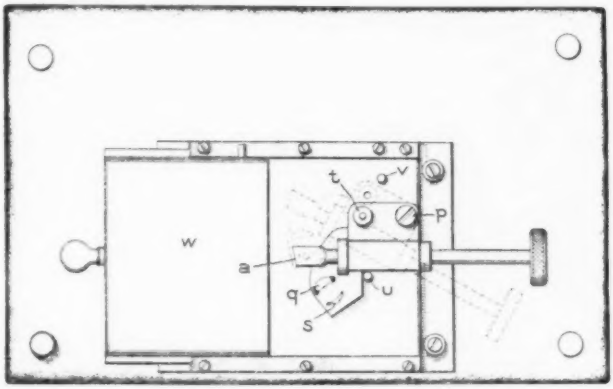

FIG. 11. *Plan view corresponding to Fig. 10.*

W is a metal cover which can be slid over the crystal carrying member, when the outfit is not in use, for mechanical protection.

Ray-Track Experiment

For use with the C. T. R. Wilson apparatus, as modified by Shimizu,[5] the x-ray unit is provided with a special metal cover carrying two diaphragms and is so placed, see Fig. 12, that the small x-ray beam defined by these diaphragms passes about an inch to one side of the expansion chamber, *y*. A circular window, *z*, of aluminum foil, 0.0025 inches thick and $\frac{3}{8}$ inches in diameter, is clamped at the periphery between two brass rings and these are fastened with Khotinsky cement in a hole drilled in the glass side-wall of the expansion chamber.

When the x-ray switch is closed, no clouds are seen in the chamber unless some source of secondary rays is interposed in the x-ray beam

[5] T. Shimizu, Roy. Soc. Proc. *99*, pp. 425-431; Aug. 2, 1921.

opposite the aluminum window, in which case scattered radiation can enter the expansion chamber.

When a piece of wood is used as the scattering agent, the clouds in the ray-track apparatus appear to have an average length of perhaps a cm, while if copper is used, most of the clouds appear to be only perhaps 2 mm long. The difference is very apparent and the short clouds are due to the *K*-radiation from the copper.

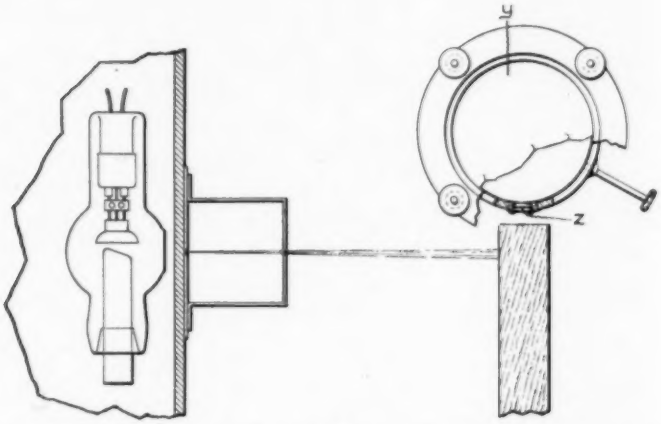

FIG. 12. *Plan view of un arranged to show x-ray scattering by means of ray track apparatus*

The Millikan Oil-Drop Experiment and a Working Model of the Same

In Fig. 13 an x-ray unit is shown in the center with the Millikan oil-drop apparatus to the right and the model to the left.

The oil-drop apparatus is essentially as described by Millikan.[6] A second, demonstration, eye-piece has been added to the telescope. The second observer uses the eye-piece *a* while the demonstrator uses the other eyepiece, *b*.

Pressure on *E* uncovers the hole in the upper plate *d*. Compressed air is admitted to the atomizer *g*, through a valve which is not shown.

The self-feeding arc-lamp, *L*, is placed in a light-tight housing, provided with ventilating loeuvres.

The room is effectively darkened.

[6] R. A. Millikan, Phys. Rev. *32*, pp. 349-397; 1911.

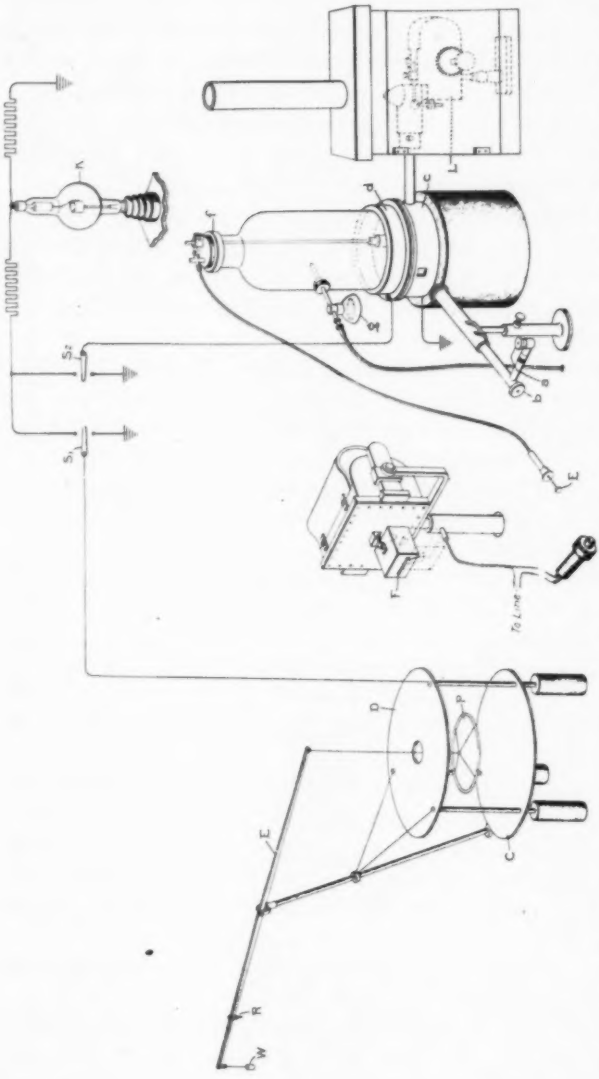

FIG. 13. *Perspective view of unit arranged to demonstrate Millikan oil drop experiment and to operate a working model of the same.*

High-voltage direct current is obtained from a transformer, not shown, and a kenotron, K.

The x-ray outfit is carried by a vertical rod which passes through the top of the table and is counter-weighted so that it can be easily raised and lowered. It is also easily rotatable about the vertical axis.

No attempt has been made to do quantitative work with this apparatus, but it has been used with great satisfaction for showing the qualitative side of the Millikan experiment.

The working model of the experiment is seen to the left of the x-ray outfit in Fig. 13. The large metal plates, C and D, correspond to the plates c and d of the Millikan apparatus. C is, like c, connected to ground while, by means of S_1 and S_2, the high tension current can be switched from d to D.

The high tension voltage is regulated by means of a rheostat which is connected in series with the primary of the high tension transformer.

The disc of paper, P, corresponds to the oil-drop and is hung by a piece of light oiled silk fish line from one end of the light wooden scale-beam, E. The paper disc is roughly balanced by the counter-weight, W, and brought to approximately the midway position between the two plates by means of the rider, R.

The experiments may be carried out as follows: Plate D is brought to $+10000$ volts. If this does not disturb P, it shows that P is uncharged.

If now, leaving D charged to $+10000$ volts, a thin beam of x-rays, defined by the rectangular slit in the diaphragm F, is passed through the air below P, the latter quickly rises showing that it has acquired a negative charge.

If the voltage of D is reduced to zero, P returns to its original position, moving upward again, however, if D is again brought to $+10000$ volts.

The negative charge may next be removed from P by bringing D to zero potential and then, with diaphragm F dropped down, as shown in the dotted position, turning a large beam of x-rays on P and the surrounding air.

That the charge has been removed is shown by the fact that upon now bringing D to $+10000$ volts P does not move.

If now using the rectangular diaphragm, and with D at $+10000$ volts, a thin beam of x-rays is passed through the air above P, it is seen that P moves downward, showing that it has acquired a positive charge.

The behavior of the piece of paper is then like that of the oil-drop. It can, at will, be made to either acquire or lose electrons.

The experiment also has this to recommend it that, unlike many static experiments, it works as well in wet as it does in dry weather.

Thermoluminescence

If a piece of fused quartz is held for a couple of seconds in the x-ray beam close to the window of the unit, and is then subsequently heated in the dark in the flame from a Bunsen burner, it is seen that, long before becoming visibly red, the quartz gives off a bright blue light.

If a strip of the ordinary calcium-tungstate intensifying screen, say an inch wide, is held, with a pair of tongs, in the x-ray beam close to the window of the x-ray outfit, one sees, in a darkened room, a brilliant blue luminescence. Upon removing the screen from the x-rays, one sees that there is but little phosphorescence. If now the screen is brought to liquid air temperature, by immersing it for a moment in a Dewar flask filled with liquid air, and then quickly placed in the x-ray beam for a few seconds, one notices, upon removing it from the beam, first a slight phosphorescence and then, as the screen warms up, a brilliant yellowish green thermoluminescence.

The experiment is much more beautiful if a platino-cyanide of barium screen is used. In this case the screen gives off green light under the influence of the x-rays and shows very little phosphorescence. If immersed in liquid air and then quickly subjected for a few seconds to x-rays it shows, upon warming up, six distinct thermoluminescent periods taking place in the following order:

Green
Light yellowish green
Reddish brown
Light green
Light reddish brown
Dark reddish brown.

EXPERIMENTAL OIL-IMMERSED OUTFIT FOR GENERAL MEDICAL DIAGNOSTIC WORK

This outfit is very similar to the dental outfit already described but differs from it in enough respects to warrant a brief description.

It is designed to operate at 30 milliamperes and 84000 volts (max.).

The x-ray generating unit, consisting of high voltage transformer, filament transformer, x-ray tube, metal container and oil, weighs 90 pounds.

The unit is shown in Fig. 14 mounted on a regular radiographic table.[7] To house the heavy counterweight, the supporting steel tube is made very large—5 inches in external diameter.

By accurate counterweighting and the use of ball bearings throughout and by arranging to have the two horizontal axes, about which the unit rotates, pass through its center of gravity, the movement of the unit at any point within its range is made easy and smooth.

FIG. 14. *High power oil-immersed outfit as arranged for general medical radiography*

The connections inside the unit are the same as in the dental unit. The outside connections are so changed that the x-ray switch controls only the current supply to the x-ray transformer. A separate switch controls the current supplied to the filament transformer.

The control stand contains the usual autotransformer, voltmeter, time-switch, milliamperemeter and adjustable Kearsley stabilizer.

[7] A special table of heavier construction would be much better for this purpose.

A flexible four-wire low tension cable, leading from the unit, is carried on a large spring-reel supported either from the ceiling or from a fixed mast attached to the table. Contact between the wires of the flexible cable and the stationary wires leading away from the reel is secured through brushes and slip-rings.

The x-ray tube is shown in Fig. 15. It is designed to operate at 30 milliamperes and 84000 volts (max.), and to have a much larger factor of safety than the regular 30 milliampere Radiator tube. The bulb is $3\frac{3}{4}$ inches in diameter and the overall length of the tube is $8\frac{1}{2}$ inches. The anode head is made large and hemispherical in shape and, to permit of more rapid heat flow to the oil, the anode stem is made very large—

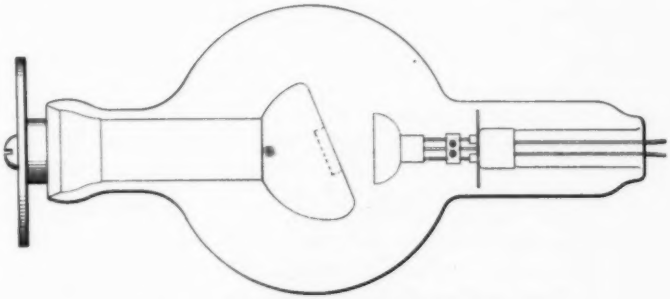

FIG. 15. *Tube used in high power outfit of Fig. 14.*

13/16 inches in diameter. To increase that portion of the anode surface which is in contact with the oil, a circular disc of copper $2\frac{1}{2}$ inches in diameter is soldered to the outer end of the anode stem.

X-ray protection is obtained by the use of lead on the outside of the metal tank containing the unit.

This outfit, because of the larger external surface of the container, is capable of continuously radiating more energy than the dental outfit. It is intended, however, for medical diagnostic work and any heavier duty than this would call for water or forced air cooling.

It is a pleasure to me to acknowledge the able assistance in this work of Mr. George Hotaling and Mr. Leonard Dempster.

RESEARCH LABORATORY,
GENERAL ELECTRIC COMPANY,
SCHENECTADY, NEW YORK.
June 18, 1924.

Observations on the Point Discharge as a Detector of Alpha Particles.—Experiments were performed with a cylindrical brass chamber terminated by a brass hemisphere, the needle coming down the axis of the cylinder with its point at the center of the hemisphere; a slit 4 mm wide, opened along a meridian of the hemisphere, was covered with thin Al foil (equivalent to 1 cm of air in stopping-power); nature and pressure of the contained gas not stated. A beam of alpha particles was sent into the chamber from various directions and so as to follow various paths within the chamber, and the number of point discharges per two-minute interval determined in each case. Surprisingly it was found that whether the beam touched or failed to touch the needle point made no difference whatever; a beam directed against the needle point but coming at right angles to the axis of the needle excited no discharges, while a beam directed parallel to the needle axis but keeping 3 mm away from it produced the full effect. Apparently what really mattered was that the beam should pass through a restricted area of the Al foil, some 3 mm in diameter, at the very top of the hemisphere; if it passed through this area the whole effect was produced irrespective of where the beam passed within the chamber. Kutzner thinks that this proves that the alpha particle acts by destroying momentarily a film which forms itself on the inner surface of the Al foil, gathers a strong negative charge during the preliminary runs with the chamber, and so inhibits the point discharge from then onward permanently unless destroyed in some such manner; it reforms itself, however, very quickly under the influence of the point discharge which the passage of the alpha particle evokes. [W. Kutzner, Berlin, Landwirt. Hochschule; ZS. f. Phys. *23*, pp. 117-129, 1924.]

K. K. DARROW

Presentation of New Fundamental Concepts and Units in Photometric Measurements.—This is an article which discusses the improvements in construction and efficiency of modern illuminants, beginning with the carbon filament lamp and carried through the gas-filled tungsten lamp. The difficulties incident to photometric comparisons of the different types, because of their widely different distribution curves, are mentioned. This is followed by an exceptionally clear and readable development of the system of photometric units which were adopted in 1922 by a committee on illumination consisting of the foremost physicists and illuminating engineers in Germany. Derivations are given to show under what conditions sources of finite area and geometrical form can be regarded as point sources. A brief account is given of recent experiments in which particular attention was paid to the physiology of the eye and its bearing on illumination problems. ["Die Behandlung der neuen Grundbegriffe und Einheiten der Lichtmessung im Unterricht," S. Fröhner (Mannheim) ZS. f. Phys. u. Chem. Untersicht, *37*, p. 145, 1924.]

PAUL E. KLOPSTEG

IMAGE CURVATURE AS A FUNCTION OF DIAPHRAGM POSITION*

By I. C. Gardner and J. J. Arnaud

Taylor's[1] formulas for the curvatures of the astigmatic image surfaces produced by a combination of elements may be written as follows:

$$\text{Primary curvature} = \sum \left\{ \frac{1}{n_K f_K} + \frac{3}{f_K} \left(1 - \frac{2C_K}{p_K - e_K} + \frac{A_K}{(p_K - e_K)^2} \right) \right\} \quad (1)$$

$$\text{Secondary curvature} = \sum \left\{ \frac{1}{n_K f_K} + \frac{1}{f_K} \left(1 - \frac{2C_K}{p_K - e_K} + \frac{A_K}{(p_K - e_K)^2} \right) \right\} \quad (2)$$

with the summation extended over all the elements of the system. The primary curvature is defined as the reciprocal of the radius of curvature of the primary image surface at its axial point, and a similar definition referred to the secondary image surface holds for the secondary curvature. If an image surface is concave toward the incident light, the curvature is positive.

Each lens is assumed to be replaced by two elements[2] which are lenses of zero thickness, of the same index as the original lens. The curvature of the first face of the first element is the same as that of the first face of the lens, and the second face of the element is plane. Similarly the element which replaces the second surface of the lens has the first face plane, and the second face has the same curvature as that of the original lens. If the lens has the thickness, t, the two elements separated by the air space t/n form a system having the same front, back and equivalent focal lengths as the original lens.

The surfaces and elements corresponding to them are numbered in order beginning with the surface receiving the incident light. A glass to glass or cemented surface received two numbers, one for the element on each side of the surface. Each odd numbered element therefore corresponds to the first surface of a lens component, and each even numbered element to the second surface. The symbols, together with the sign conventions are given below:

n = index of refraction of element.

f = focal length of element.

* Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce.

[1] Taylor—A system of Applied Optics, Macmillan & Co. Ltd. Section VI.

[2] Ibid—Section II.

$f = \pm \frac{r}{n-1}$. The plus sign is to be used for all elements which have the second surface plane, i. e., for all odd numbered elements, the negative sign for all even numbered elements.

r = radius of curvature of surface of the lens. The sign of r is positive if the surface is convex toward the incident light.

A = coefficient of spherical aberration, defined by the equation

$$A = \frac{n+2}{n(n-1)^2}s^2 + \frac{4(n+1)}{n(n-1)}sp + \frac{3n+2}{n}p^2 + \frac{n^2}{(n-1)^2} \tag{3}$$

C = coefficient of coma, defined by the equation

$$C = \frac{n+1}{n(n-1)}s + \frac{2n+1}{n}p \tag{4}$$

s = shape factor, which is $+1$ for any odd numbered element, i.e., for any element with its second surface plane and -1 for any even numbered element.

p = position factor, defined by the equation

$$p = -\frac{2f}{u} - 1 \tag{5}$$

e = eccentricity factor, defined by the equation

$$e = -\frac{2f}{d} - 1 \tag{6}$$

u = distance on the axis from the element to the projection of the object point.

u' = distance on the axis from the element to the projection of the image point.

d = distance on the axis from the element to the entrance pupil point.

d' = distance on the axis from the element to the exit pupil point.

Any of the four lengths just defined is positive if a generating point, when moving in the direction of the incident light, passes through the vertex of the element before it arrives at the outlying end of the length.

Subscripts are used to indicate the surface or element to which any of the above quantities refer.

If all the lenses of the system are in contact and are assumed to be of zero thickness, an important simplification in formulas 1 and 2 can be made. From equations 5 and 6,

$$p_1 - e_1 = 2f_1\left(\frac{1}{d_1} - \frac{1}{u_1}\right) \tag{7}$$

Also

$$p_2 - e_2 = 2f_2\left(\frac{1}{d_2} - \frac{1}{u_2}\right) \tag{8}$$

but as the elements are in contact and of zero thickness

$$\frac{1}{d_2} = \frac{1}{d'_1} = \frac{1}{d_1} + \frac{1}{f_1} \tag{9}$$

and

$$\frac{1}{u_2} = \frac{1}{u'_1} = \frac{1}{u_1} + \frac{1}{f_1} \tag{10}$$

Therefore equation 8 becomes

$$p_2 - e_2 = 2f_2\left(\frac{1}{d_1} - \frac{1}{u_1}\right) \tag{11}$$

and in general

$$p_K - e_K = 2f_K\left(\frac{1}{d_1} - \frac{1}{u_1}\right) \tag{12}$$

Substituting from equation 12 in equations 1 and 2

$$\text{Primary curvature} = \sum\left(\frac{1}{n_K f_K} + \frac{3}{f_K}\right) - \left(\frac{3d_1 u_1}{u_1 - d_1}\right)\sum\frac{C_K}{f^2_K} + 3\left(\frac{d_1 u_1}{u_1 - d_1}\right)^2 \sum\frac{A_K}{4f^3_K} \tag{13}$$

$$\text{Secondary curvature} = \sum\left(\frac{1}{n_K f_K} + \frac{1}{f_K}\right) - \left(\frac{d_1 u_1}{u_1 - d_1}\right)\sum\frac{C_K}{f_K{}^2} + \left(\frac{d_1 u_1}{u_1 - d_1}\right)^2 \sum\frac{A_K}{4f_K{}^3} \tag{14}$$

In a large number of the cases met with in practice u_1 is infinite or so large in comparison with d_1 that one may write, to a satisfactory approximation,

$$\text{Primary curvature} = \sum\left(\frac{1}{n_K f_K} + \frac{3}{f_K}\right) - 3d_1 \sum\frac{C_K}{f_K{}^2} + 3d_1{}^2 \sum\frac{A_K}{4f_K{}^3} \tag{15}$$

$$\text{Secondary curvature} = \sum\left(\frac{1}{n_K f_K} + \frac{1}{f_K}\right) - d_1 \sum\frac{C_K}{f_K{}^2} + d_1{}^2 \sum\frac{A_K}{4f_K{}^3} \tag{16}$$

From these last two equations it is evident that, if the curvatures are plotted against d, one obtains two parabolas, with axes perpendicular

to the d axis, and intersecting at two points for which the curvatures are equal to the Petzval curvature, i. e., $\sum \frac{1}{n_K f_K}$. Such a graph is shown in Fig. 1. The dotted curve gives the curvature of the secondary, the solid curve the curvature of the primary image surface. These curves are for eye-lens No. 1 (see below) with the thickness of the crown component set equal to 0. Such graphs are particularly useful in the design of an eye-piece. If the course of the light is assumed to be re-

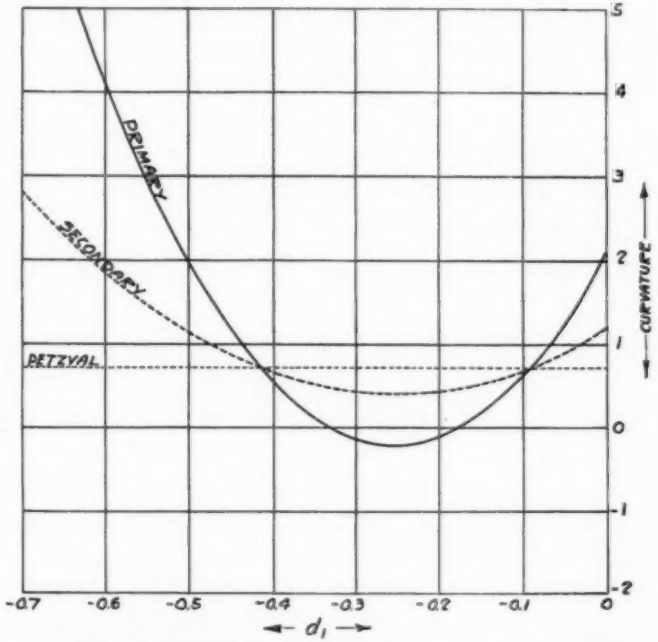

FIG. 1. *Primary and secondary curvature of eye-lens No. 1, by Taylor formulas.*

versed in direction, for the eye-lens the object is at an infinite distance (for telescopic adjustment) and d_1 is the distance from the eye-lens to the exit-pupil of the telescope, which is the image of the objective as formed by the entire eye-piece. In the ordinary Kellner eye-piece the eye-lens is a cemented doublet of crown and flint and it is well known that the curvature of field for the entire eye-piece can be altered greatly by changing the power of the field lens or altering the distance between the eye-lens and field lens. This change introduces a change of curvature chiefly because it alters the value of d_1, and the amount

of the change can be readily determined by a graph plotted from equations 15 and 16.

Below there are given the formulas for two typical doublets obtained in the preliminary design of an eye-lens.[3]

	No. 1	*No. 2*
r_1 (plane)[4]	∞	∞
$t_{1,2}$	0	0
$n_{1,2}$	1.656	1.656
r_2 (concave)	+.546	+.425
$t_{2,3}$	0	0
$n_{2,3}$	1.000	1.000
r_3 (convex)	+.546	+.425
$t_{3,4}$	.125	.125
$n_{3,4}$	1.520	1.520
r_4 (convex)	−.425	−.404

In Fig. 2 the dotted curve shows the value of the primary curvature for eye-lens No. 1 as obtained by equations 15 and 16 when all the thicknesses are assumed to be zero and d_1 is measured from the common vertex of all the surfaces. To avoid confusion on the graph the corresponding curves for the secondary image surface are omitted. In general the approximation is better for the secondary than for the primary curve. It will be noted that the values of d_1 are negative, as the light is assumed to be passing through the eye-lens in a direction opposite to that of actual use. The line of dashes shows the value of the primary curvature as obtained by the more exact equation (1), in which the thickness of the crown component is not neglected. The thickness here is relatively large, as it is one-eighth of the focal length, and the alteration in the curve when thickness is taken into account is large. From the simple equations applying to the lens of zero thickness many of the effects resulting from different changes in the lens can be investigated qualitatively. The curve drawn in full shows the curvature as determined by the trigonometric method. In the determination of this curve several values of d_1 were selected. For each value of d_1 a ray making an angle of 20° with the axis at the pupil point was traced through the lens and the astigmatic images of an infinitely distant point produced by a pencil of vanishing aperture proceeding along this ray path were determined by the usual formulas. Let

[3] Two subscripts indicate that the quantity is referred to the medium lying between the two corresponding surfaces, thus $t_{1,2}$ = axial thickness of medium lying between the first and second surfaces; $n_{1,2}$ = index of refraction of this medium.

[4] As the first surface is plane the thickness of the flint has negligible influence upon the curvature and it has therefore been set equal to zero.

$(y'_4)_{20°}$ be the distance of the image point from the axis of the lens, and let $(z'_4)_{20°} = (u'_4)_{0°} - (u'_4)_{20°}$, where $(u'_4)_{0°}$ is the distance from the vertex of the fourth surface to the image of an infinitely distant axial point, and $(u'_4)_{20°}$ is the distance from the vertex of the fourth surface to the projection on the axis of the image of the infinitely distant point

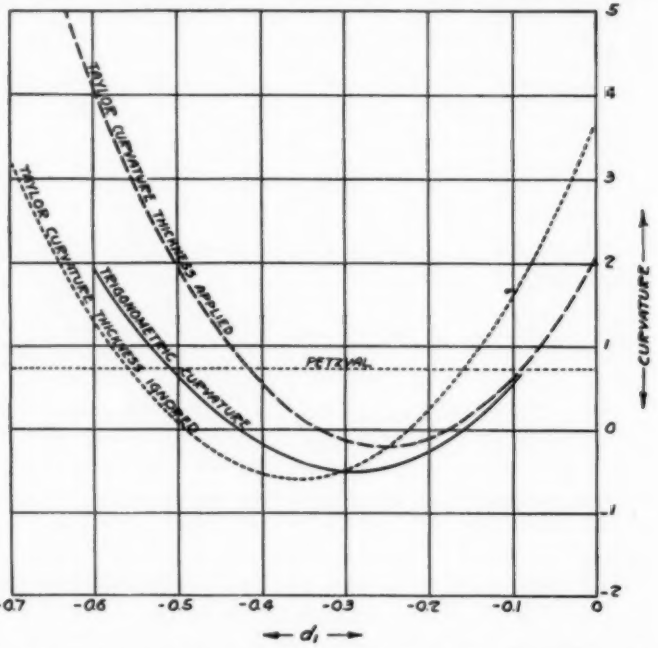

FIG. 2. *Primary curvature of eye-lens No. 1 by Taylor formula and by trigonometric computation.*

20° from the axis. These lengths are illustrated by Fig. 3. For either image surface, if the appropriate z'_4 (primary or secondary) is employed, we may define the curvature by the equation

$$(\text{Curvature } 20°) = \frac{(z'_4)_{20°}}{(y'^2_4)_{20°}} \tag{17}$$

This is actually the curvature, at its vertex, of the parabola passed through the axial image point and the image of a point 20° from the axis, and will be designated as the curvature of field for 20° or briefly (Curvature 20°).

This definition of curvature for an oblique object point is illustrated in Fig. 3. The image of an object point 20° from the axis is at O' and the axial image at I'. A section of the image surface is represented by

the curved line joining O' and I'. The dotted line is a parabola symmetrically placed with respect to the axis and passed through these same two points. It is evident that the curvature as defined by equation 17 is the curvature at the vertex of the parabola. If the section of the image surface were parabolic, as it is on the basis of third order equations, the curvature as defined would be independent of the distance of object point from axis. In general the section is not a parabola and the curvature approaches a limiting value as the object point approaches the axis, which is the value based on the third order system of equations.

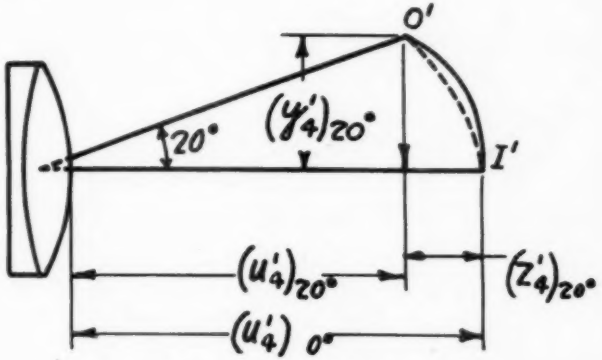

FIG. 3. *Lengths involved in definition of curvature.*

A reference to Fig. 2 shows that even when the spacing of the elements is taken into account the curves representing the third order curvature resemble parabolas with the axes vertical. As the distance of pupil point from the lens becomes greater, d_1 increases negatively and the trigonometric curve departs from the Taylor curve. This is to be expected, as with an increase of eccentricity the effect of the higher order aberrations will become greater. It is indeed remarkable that the curves agree as well as they do qualitatively throughout the entire range shown on graph, and, to a useful degree, quantitatively from $d_1 = 0$ to $d = -.3$ which is perhaps the entire extent of the useful range. Curves analogous to those of Fig. 2 for eye-lens No. 2 are shown in Fig. 4. In eye-lens No. 2 the cemented curve is steeper and the agreement is not so good as before. But even here a great deal of useful information can be gained from the Taylor curve which can be obtained much more easily than the curve based on trigonometric computations, and the agreement may be expected to be much better when one is dealing with fields of less angular extent.

In order to illustrate the manner in which the discrepancy between the trigonometric and Taylor curvatures increases with increase of field under consideration, the curvature, in accordance with definition given above, has been computed trigonometrically for fields having half angles of 10°, 20° and 30°. By an obvious generalization it is

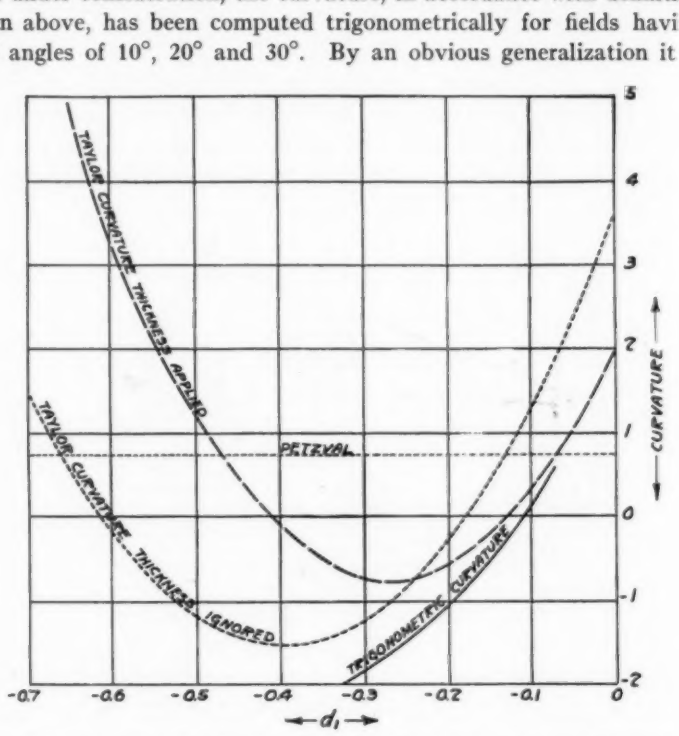

FIG. 4. *Primary curvature of eye-lens No. 2 by Taylor formula and by trigonometric computation*

evident that the curvature given by Taylor's formula is for a field of 0°. The data for the eye-lens selected is given below:

Eye Lens No. 3

r_1 (plane)	∞
$t_{1,2}$	.062
$n_{1,2}$	1.662
r_2 (concave)	+.574
$t_{2,3}$	0
$n_{2,3}$	1.000
r_3 (convex)	+.574
$t_{3,4}$	.123
$n_{3,4}$	1.521
r_4 (convex)	.427

The value of the primary curvature is plotted in Fig. 5. The curvatures for points at different distances from the axis differ materially which indicates that a meridian section of the image surface is not a parabola. The increased separation of the curves for greater angular distances from the axis and for greater pupil distance indicates that the higher

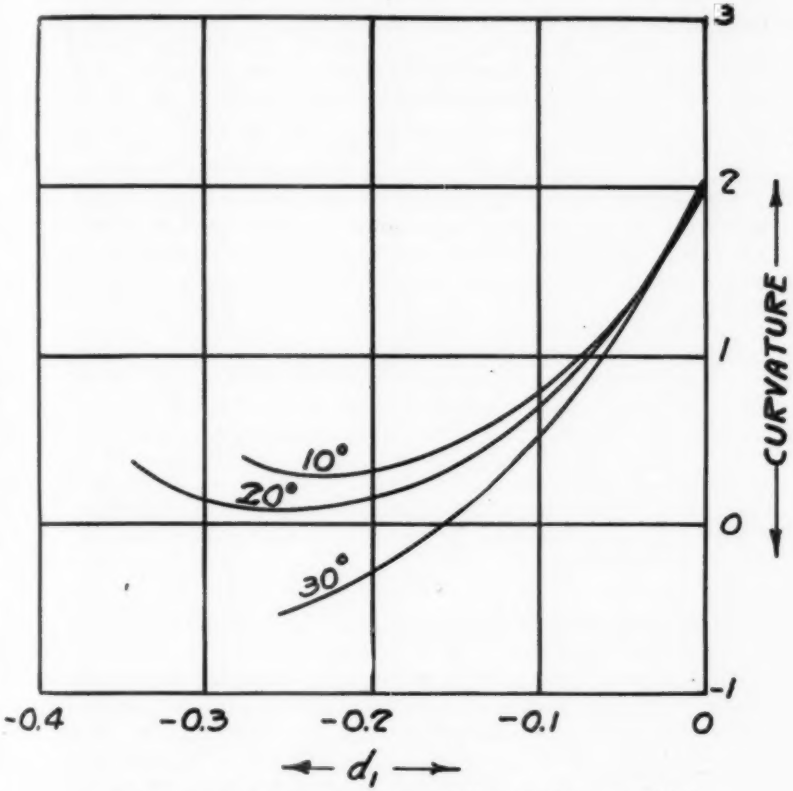

FIG. 5. *Curvature as a function of distance of object point from center of field.*

order curvatures increase more rapidly as the distances from center of field and the eccentricity increase. The corresponding curvature as computed by Taylor's formula so nearly coincides with the curve for 10° that it is impracticable to indicate it separately on the figure.

BUREAU OF STANDARDS
WASHINGTON, D. C.

Dissociation of Hydrogen and Nitrogen Molecules by excited mercury atoms.—Hydrogen and nitrogen at pressures of the order of magnitude ½ mm (in the cases where the pressure is stated) were mingled with mercury vapor in equilibrium with liquid mercury at temperatures of 150°-235°C, and low voltage arcs operated in the mixtures between a hot cathode and a cold anode. Cupric oxide was provided within the tube to fasten down any hydrogen atoms and magnesium to take any nitrogen atoms; the hot filament also can be expected to remove atomic nitrogen from the gas. As the low voltage arc is operated the pressure diminishes, and this is attributed to the removal of the atoms produced by the dissociation of the H_2 (or N_2) molecules in collisions with mercury atoms previously put into a metastable or "excited" state by electron impacts. The data in each measurement consist of values of pressure taken once a minute during the maintenance of the arc; unfortunately the hot filament also dissociates molecules (of H_2) at a certain rate, which must be determined by control experiments and allowance made for it. Although the results do not seem to be accurately reproducible, the rate of disappearance of hydrogen in a 5.3 volt arc in the hydrogen mercury mixture is distinctly greater than that in a 10.4 volt arc in the mixture, and this in turn distinctly greater than that in an arc operated at higher voltages in pure hydrogen. With nitrogen the effect is feebler, i. e. the rate of disappearance is less in absolute measure; but the gas disappears more rapidly from a mixture with mercury, sustaining an arc at a low voltage, than when it is pure and sustains an arc at a voltage between 17 and 30. At higher voltages in nitrogen the rate of disappearance in pure nitrogen increases and there are strange luminous and chemical effects. [O. S. Duffendack, Michigan, and K. T. Compton, Princeton; Phys. Rev. (2) *23*, pp. 583-592, 1924.]

K. K. DARROW

Spektroskopie der Rontgenstrahlen.—By Manne Siegbahn. 257 pages, 119 illustrations. Julius Springer, 1924.

This work is written mainly from the experimental standpoint. About half of the book is devoted to descriptions of various types of spectrographs and spectrometers and their methods of use in x-ray wave length determinations. In the remaining chapters are tabulated lists of wave lengths of emission lines and absorption limits together with their discussion and correlation into series. Tables of ν/N and $\sqrt{\nu/N}$ are given for all known limits obtained directly; by application of the combination rules; and by interpolation and extrapolation when reasonably certain. This work is a veritable mine of experimental material. Everyone interested in x-ray spectroscopy should possess a copy. Prof. Siegbahn, who has done so much in extending our knowledge of x-ray spectra, is to be congratulated upon compiling the vast quantity of existing data in convenient form.

PAUL D. FOOTE

A FLEXURE MICROBALANCE

By C. B. Bazzoni

A number of microbalances have been described in the literature in which the principles of the beam balance have been developed to an extreme degree. For example the quartz fiber beam balance of Steele and Grant[1] modified by Pettersson[2] is said to detect changes of 0.25 $\times 10^{-6}$ mg in a load of 250 mg i.e. of one part in 10^9. Such balances are difficult to construct and to adjust but are apparently steady and dependable.[3] Salvioni[4] has described a microbalance of a different type employing the principle of Hooke's law in which the movements of a horizontal flexed glass fiber bearing the load were followed with a microscope. This balance was claimed to be dependable to 1/1000 mg with a load of 100 mg, that is, to one part in 10^5. The principle of flexure can be applied in a variety of devices which recommend themselves through simplicity in construction and adjustment. The present note describes a simple flexure balance designed and built in this laboratory twelve years ago to measure the vapor pressure of certain solids. It is capable of measuring changes in weight of 1/100000 mg in a load of one milligram.

The balance consists essentially of a quartz fiber supported at one end. The free end of the fiber is provided with a scale pan which can be kept under observation in a micrometer microscope. The general construction is sufficiently well shown in the photograph, Fig. 1. The beam chamber is a glass bottle laid horizontally. The bottom has been cut off, the walls flanged and a plate glass affixed with hard wax. The ground stopper in the neck of the bottle is fitted with a tubular capillary extension into which the stem of the quartz fiber is fastened. It is obviously of the greatest importance that this beam should be fastened in such a way that it can not shift through temperature changes or through strains or through viscosity of a cement. Plaster of Paris may be used or a socket of brass or nickel with screw settings according to the use to which the balance is to be put. The fiber is adjusted so that its free end is immediately inside the plate glass end but not touching it. A square piece of very thin glass three millimeters on an edge is

[1] Steele and Grant, Proc. Royal Soc. Series A, *82*, p. 580; 1909.
[2] Pettersson, Proc. Phys. Soc. Lond., *32*, p. 209; 1920.
[3] Hartung, Phil. Mag., *43*, p. 1056; 1922.
[4] Salvioni, Nuovo Cimento, *3*, p. 386; 1902.

cemented to the end of the beam on top. This glass is obtained by blowing to pieces a bulb of glass after heating in a flame. In the wall of the bottle near the plate glass end is a second wide stopper ground into a neck through which the pan may be reached for the adjustment of the load. At the sides of the bottle tubes are fuzed on and brought up at right angles with stopcocks as shown. At the neck end is a similar tube with a ground cone for a drying capsule. These tubes are carried up well above the level of the body of the bottle so that the whole chamber may be immersed in an oil bath for temperature control. The bottle is mounted on a massive cast iron base on which it can be shifted

FIG. 1. *Quartz fiber flexure micro-balance.*

into any desired position and then rigidly clamped. The micrometer microscope is provided with a micrometer screw for moving it bodily up and down as well as with the usual micrometric cross hairs. The microscope is set in line with the axis of the bottle so that it can be focused on the end cross section of the fiber.

This design has a number of special features. The load on the pan may be maintained indefinitely in an atmosphere of any desired gas or in a vacuum or in a current of gas and can be held at any desired temperature. The particular pattern here described lends itself readily to vapor pressure measurements since the total volume may be accurately determined and the temperature and vacuum controlled. If constructed at the present time the bottle would be made of pyrex with

a pyrex plate fuzed on so that temperatures above the melting point of the wax could be used if desired.

In use the beam is calibrated by putting known weights on the pan and assuming the validity of Hooke's Law which, for the flexures used, is entirely justifiable. A similar balance, differing from the one described above in arrangement, was used by the author[5] to measure the loss of weight of musk in which work a sensibility of 0.00007 mg per head division was employed.

Consideration of the construction of this balance shows that by the use of very thin fibers of quartz of considerable length and of a sufficiently powerful and accurate micrometer microscope a high paper sensibility could be obtained of the order of a millionth of a mg per head division. In the balance shown in the photograph the quartz fibers used average 0.1 mm in diameter and 10 to 12 cm in length. A load of one mg deflects such a beam about one centimeter. The reading microscope has a constant of the order of 0.00005 mm per head division. The cross hairs are focused on some definite detail in the large image of the end of the fiber as seen in the eye piece. The selected detail can be followed with certainty so that one might expect to attain a high degree of precision in settings. Practically sensibility limitations are set by mechanical tremors, by drifts due to temperature variations in the fiber and by the impossibility of using a short focus objective because of the interposition of the plate glass. It is in practice so difficult to obtain dependable readings to 1/100000 mg in a milligram load that this may be given as the extreme useful limit of the device. With ordinary precautions load changes of 1/10000 mg may however be measured with certainty.

When glass fibers are used errors arise through drifts due to viscosity and to fatigue of the fiber but quartz is free from these troubles. If a flat pan on the end of the beam is used, as described above, errors during manipulation frequently result from movements of the load along the pan or through putting the center of gravity of the load in a different place from that previously occupied by the center of gravity of the calibrating weight. These troubles can be eliminated by using a pan suspended from a definite point on the beam.

This type of balance is limited to handling small loads, as compared with the beam type of balance, if a high sensibility is to be attained. Furthermore it is adapted to following small changes in weight rather

[5] Bazzoni, Jour. Franklin Inst., *180*, p. 463; 1915.

than to making accurate weighings of applied loads. In fact, due to evident difficulties in calibration, it will not ordinarily serve as a precise weighing balance. Its special use is in following weight changes in a volatile load since the conditions of evaporation can be closely controlled.

RESEARCH SECTION,
RANDAL MORGAN LABORATORY,
UNIVERSITY OF PENNSYLVANIA.

Modifications of the Point-Discharge Method for detecting charged Particles and Quanta.—In one modification the wall of the chamber (a cylinder 2 cm in diameter with an aperture in the center of the base, the needle projecting along the axis of the cylinder to a point 1 cm from the base) is connected through a 1500-volt source to the filament of a triode; the needle is connected directly to the grid; the plate is connected to the filament through a 20-volt B-battery and a high resistance telephone receiver. A point discharge causes a momentary charging up of the grid, which is quickly annulled by electrons flowing into the grid; a sharp click is heard in the telephone. As a radioactive substance is brought close to the aperture of the chamber, clicks are heard which rapidly increase in frequency, until finally they merge into a "hissing sound of indeterminate pitch." With a low frequency amplifier these clicks or the hissing sound can be amplified to be heard throughout a room. Various striking demonstrations can be performed; the sharply limited range of alpha particles from a particular substance is clearly demonstrated; if the substance is slightly farther away from the chamber than the range of its alpha particles in air, nothing is heard, but clicks can be obtained if the intervening air is warmed with the hand or displaced with a jet of illuminating gas; if the substance is just within the range, the clicks can be stopped by displacing the air with ether. If the wall of the chamber (instead of the needle) is connected to the grid, this receives negative instead of positive charge at each point-discharge; the arrangement has certain practical advantages and certain consequences both convenient and inconvenient, e. g. a too rapid succession of discharges is not recorded at all, as the negative charge of the grid remains too high to let any plate current through between the impulses. Photographic records taken with this arrangement, a moving coil galvanometer replacing the telephone, are reproduced; they correspond in individual cases to alpha particles, beta particles, gamma rays, and photoelectrons excited from the needle by irradiation with a quartz-enclosed mercury arc. Discharges of differing origin are distinguished by the appearance of the record, as well as the loudness of the acoustic effect. [H. Greinacher, Zürich; ZS. f. Phys. *23*, pp. 361-378, 1924.] K. K. DARROW

A MULTIPLE RANGE McLEOD GAUGE

By O. S. Duffendack and Frank Schaefer

The accompanying diagram illustrates a design for a multiple range McLeod gauge that is simple to make and easy to use. The model is not new, but so much interest has been manifested by visitors who have seen such gauges in use at the University of Michigan that it seems worth while to again call attention to it. Similar gauges are used at the Bureau of Standards and probably at other laboratories.

The usual range of the McLeod gauge is extended by employing a method first described by Kahlbaum.[1] The mercury is raised to some fixed mark, B, on the capillary, and the height of the mercury in the auxiliary capillary is noted. The pressure of the gas is a linear function of the difference in level of the mercury in the two capillaries. The range is further extended by blowing a secondary bulb in the capillary in order to increase the ratio of the final volume to the initial volume of the imprisoned gas. The mercury is then raised to level A in the capillary between the bulbs and the height of the mercury in the auxiliary capillary noted as before. Again the pressure of the gas is a linear function of the difference in the mercury levels. This use of a secondary bulb is a modification of the method for increasing the ratio of the volumes of the imprisoned gas first described by Zehnder.[2]

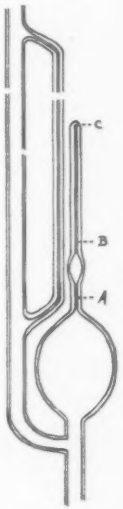

Fig. 1

The formulae for the three ranges of the gauge are as follows:

a = cross section of capillary AC.
l = length of capillary BC.
l' = length AC.
V = volume of large bulb.
v = volume of small bulb.
V_0 = total volume = $V+v+al$.
d = depression of mercury in capillary below C when mercury in auxiliary is raised to level C.

[1] Zeit. f. Instrumentenkunde *15*, p. 191, 1895.
[2] Ann. d. Physik *10*, p. 643, 1903.

h = height of mercury in auxiliary capillary above C when mercury is raised to A or B.

p = initial pressure of the gas.

Applying Boyle's law we get:

1. When the mercury is raised to level C in the auxiliary capillary,

$$p = \frac{a}{V_0} d^2 .$$

2. When the mercury is raised to B in the capillary,

$$p = \frac{al^2}{V_0} + \frac{al}{V_0} h = \alpha + \beta h .$$

3. When the mercury is raised to A in the capillary,

$$p = \frac{l'(al+v)}{V_0} + \frac{al+v}{V_0} h = \alpha' + \beta' h .$$

We make the gauge direct reading as follows: A piece of millimeter cross-section paper is mounted behind the gauge from A to the top of the auxiliary capillary. Vertical scales for d and h are constructed below and above C and the three formulae are plotted with convenient horizontal scales for p. Formula (1) is plotted several times with different decimal multipliers to facilitate the reading of this scale. One horizontal scale from 0 to 100 will suffice for all the scales for formula (1). When negative values of h are used, the scales overlap. By a proper choice of capillary and bulbs, the gauge can be made to read from a fraction of a micron to several millimeters. Obviously, the range can be extended by adding another bulb.

PHYSICS LABORATORY,
UNIVERSITY OF MICHIGAN.

Further Investigations on the Ions produced by Electron-impacts against Hydrogen Molecules.—Method originally devised by Smyth. The primary product of ionization in the neighborhood of 17 volts is H_2^+; but at comparatively high pressures H^+ and H_3^+ appear and become relatively more important; the relative amounts, however, depend on the magnitude of the field used to accelerate the ions after their formation. Ions for which $m/e = 1/2$ and $1/3$ the value characterizing the hydrogen nucleus are apparently observed, but the observations are interpreted as meaning that H_2^+ and H_3^+ molecules drop apart as they pass out of the accelerating field into the magnetic field, the fragments however retaining the direction and velocity of the original molecules (!) [H. D. Smyth, Princeton; Nature *114*, p. 124, 124.]

K. K. DARROW

ATTACHMENT FOR WATER COOLING TUBULAR RHEOSTATS

By C. B. Bazzoni

The tubular slide contact rheostat which is in almost universal use in laboratories has in the usual sizes a limited current carrying capacity. This is frequently disadvantageous both when the rheostat is used in series with the load and especially when it is used as a potential divider in which case, a high resistance rheostat being necessarily used, the end of the winding often fuses when the slider is set near the end. Many experimenters have adopted an obvious remedy by water cooling the tubes or by immersing them in oil baths. A water cooled pattern has in fact, been on the market for some time past. We have in this laboratory devised a simple and practical attachment, illustrated in the accompanying photographs, for converting ordinary rheostats into water cooled ones.

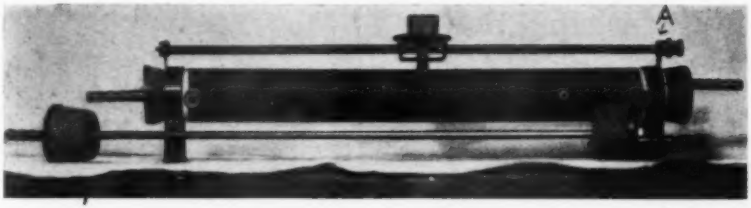

Fig. 1. *Attachment for water cooling rheostats.*

Two solid rubber stoppers (No. 9 for ordinary 14 inch by 1½ inch tubes) are bored with two holes each, one central, the other eccentric. A quarter inch brass rod threaded at the ends and fitted with nuts is put through the central holes of a pair of stoppers with wide washers under the nuts. A tubulated brass tube is soldered into each washer and is fitted through the other stopper hole. When these stoppers are brought into place in the ends of the rheostat tube by screwing down the nuts along the rods a sturdy apparatus is formed which stands high water pressures without leakage or danger of flooding. A set of stoppers can, of course, readily be removed from one rheostat and put into another so that all the stock rheostats in the laboratory are thus rendered potentially water cooled.

An alternative design is to use a brass tube stopped near the middle with solder and bored through the side walls near the ends as shown in the sketch, Fig. 2. The tube itself is threaded to carry the end nuts. The threads serve also to hold the water hose in position. This design requires only a single hole in the stopper and is more easily made. It is desirable to alter the end bearing of the slide carrier, *A*, so that the

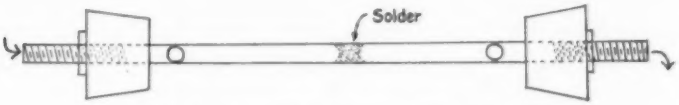

FIG. 2. *A second type of water cooling attachment.*

rod is free to move slightly endways. This obviates variation of or interruption of the contact against the coil which might result from bowing up of the slide carrier under the temperature changes.

When so fitted the current carrying capacity of the rheostats is at least trebled.

RESEARCH SECTION,
RANDAL MORGAN LABORATORY,
UNIVERSITY OF PENNSYLVANIA.

Singing Tube.—The author describes an experiment made with a singing tube attributed by Tyndall to de la Rive. A glass bulb, which may have a diameter up to 4 cm, has a tubular glass stem somewhere between 5 and 100 cm long and 2 to 7 mm in diameter. A drop of water is put in the bulb and very gently heated by means of a small flame. The tube is inclined about 30° from horizontal. A small drop forms at the juncture of the tube and the bulb and this drop emits a singing tone. The author in his investigation has determined the relation between pitch and the dimensions of the tube and bulb. The curves showing his results should be consulted for particulars. He has also established the fact that the tone emitted is a complex tone having two distinct pitches. Tones of the two pitches are independently produced by gently blowing across the tube and by blowing somewhat harder, respectively. A sensitive flame indicates strong vibration of the air column within the tube. The singing is explained on the basis of periodic evaporation and condensation of the water. ["Ein alter Versuch und ein neuer Fall des Flammensingens," Z. Gyulai, Zeitschrift für den Physikalischen und Chemischen Unterricht, *3*, p. 183; 1924.]

PAUL E. KLOPSTEG

HEAT TRANSFER BY CONVECTION*

By T. S. Taylor

In considering the exchange of heat by convection between fluids and any media, we may think of the phenomenon taking place either by free or forced convection. In free convection, the exchange of heat or molecular energy, gives rise to a variation in density of at least one of the media. This results in the establishing of fluid currents as the denser layers of the fluid displace the less dense layers. So long as the exchange of heat maintains a difference in density, the fluid currents will be maintained. The velocity of the fluid in the currents will be determined by the magnitude of the difference in the density maintained, the physical properties of the fluid, and the size and shape of the configuration of the boundary between the media. In forced convection, air currents are established in a fluid from other causes than that of the creation of a difference in the density from the gain or loss of heat energy. In either case, however, heat energy is absorbed from a medium by the fluid stream at one point and carried along as molecular energy and then given up at another point in the fluid stream.

A complete mathematical solution of any heat convection problem would require a knowledge of the hydrodynamic laws of viscuous fluids for stream line and turbulent motion, together with the fourier equations of heat conduction in a moving medium. The problem of turbulent fluid motion has been attacked by Stokes, Kelvin, Rayleigh, Reynolds, and others, and as yet no satisfactory solution has been reached. Lamb's Hydrodynamics, 3rd edition, page 591, gives the main features of their work. So far this theoretical work on convection has usually assumed the existence of an inviscid fluid. Russell[1] gives a good summary of this theoretical work on heat transfer. The theoretical results obtained from the assumption of an inviscid fluid are in general far from the experimental facts.

* One of a series of reports prepared at the request of the Committee on Research Methods and Technique appointed by the Division of Physical Sciences of the National Research Council. It is the purpose of these reports to present in brief outline a summary, more or less critical, of the methods which may be employed in various kinds of Physical measurements. See Editorial in this Journal *9*, p. 410; 1924.

[1] Phil. Mag. *20*, pp. 591-610; Oct. 1910.

[2] 1. Irving Langmuir—Phys. Review, *34*, No. 6 p. 401; 1912.
2. Irving Langmuir—A.I.E.E. *31*, Part 1 p. 1229, 1912.
3. Irving Langmuir—A.I.E.E. *32*, Part 1 p. 301, 1912.
4. Irving Langmuir—Trans. Am. Elec. Chem. Soc. *23*, p. 299; 1913.

A study of this problem by Langmuir[2] led him to the conclusion that the viscosity of the medium is a factor which cannot be neglected. Consequently he adopted a film theory as an approximation in explaining the mechanism of the transfer of heat from the one medium to the other in one of which the convection currents exist. When for example a horizontal wire is maintained at a given temperature in a fluid, the fluid adjacent to the wire becomes heated and rises as a result of its change in density, while the cooler fluid of greater density flows in to take its place. This difference in density results in a convection current being set up between the hot and cold fluids. This is usually referred to as free convection. The mechanism of the transfer of heat from the wire to the fluid in forced convection is considered to be similar to that for free convection. This film theory involves the idea that as we proceed from the surface of the wire, the velocity of the convection currents increases from zero at the wire until a point is reached at which the critical velocity conditions are exceeded and stream line flow changes into turbulent motion. This discontinuity between stream line flow and turbulent motion constitutes the outer boundary of the film. At the inner surface, the fluid has the temperature of the hot surface, and at the outer boundary of the film the temperature of the surrounding fluid. While the example referred to here has been that of a wire, the same sort of reasoning will apply as will be seen later to other shaped objects. The problem of convection has thus been reduced to one of conduction in a steady state through a film separating the media.

The question of how the film thickness varies with the size and shape of the boundary separating the two media and the properties of the fluid in which the convection currents are established can be determined by the use of dimensional reasoning. In view of the fact that no satisfactory solution of the heat losses by convection seems feasible by the use of purely theoretical hydrodynamical reasoning, it is fortunate that the use of dimensional reasoning leads to equations which seem to satisfy experimental results fairly well. An attempt has been made by A. H. Davis,[3] to obtain a solution of the problem of the convection of heat by the methods of dimensional reasoning, using as his basis certain general hydrodynamic considerations which do not take into account the existence of a stationary film. Without doubt, the equations obtained by Davis come closer to fitting the experimental facts than any

[3] Phil. Mag. *40*, p. 692, 1920; Phil. Mag. *41*, p. 899, 1921; Phil. Mag. *43*, p. 329, 1922; Phil. Mag. *44*, p. 920, p. 940, 1922.

others thus far derived from hydrodynamic considerations. His results will be referred to later.

Numerous investigators have from time to time studied the loss of heat by convection in an endeavor to obtain solutions suitable for their immediate problems. These methods have not up until recently led to any generally applicable empirical laws. Chester W. Rice,[4] however, has given a very complete and comprehensive treatment of both free and forced convection losses. He has given very detailed information on his experimental data, and how he has made use also of all other available data to test out his formulae which were derived from physical facts and dimensional reasoning. Rice gives very detailed references to the sources of his information which he utilized in his discussion. The same issue of Industrial and Chemical Engineering that contains Rice's last mentioned paper, has several articles by other writers in which the idea of a film concept is utilized in special cases. Again, the question of the heat transfer for water flowing inside pipes has been very well discussed by McAdams and Frost.[5]

FREE CONVECTION

Since the results obtained by Rice are of general application and represent the most useful ones thus far available, a discussion of the main points discussed by him will be given here. We will first take up a consideration of Rice's results on free convection. The general expression for effective film thickness was found for this case to be

$$B = KD\left(\frac{k}{\mu C_p}\right)^m \left[\frac{\nu}{(ag\Delta t)^{1/2} D^{3/2}}\right]^n \text{ cm.}$$

K is an experimental constant depending on the system of similar bodies under consideration. D is the characteristic linear dimension of the body in *cm*; k is the heat conductivity at the average temperature in watt $cm^{-1}\,°C^{-1}$; μ is the viscosity of the fluid at the average temperature in cm^{-1} gram sec^{-1}; C_p is the specific heat at constant pressure for average temperature in joule $gram^{-1}\,°C^{-1}$; m is an experimental exponent; ν is $\frac{\mu}{\rho}$ or the kinematic viscosity of the fluid for an average temperature in $cm^2\,sec^{-1}$; a is the coefficient of density change per degree centigrade for an average temperature in °C; for an ideal gas $a = \frac{1}{273}$; g is the

[4] Proceedings of A.I.E.E., Swampscott, Mass., June 26-29, 1923; Proceedings of A.I.E.E. Phila., Pa., Feb. 4-8, 1924; Industrial and Engineering Chemistry, *16*, No. 5, p. 454; 1924.

[5] Refrigerating Engineering, *10*, No. 9, pp. 323-334; 1924.

acceleration of gravity = 980 cm/sec^2. Δt is the temperature difference between the surface and ambient fluid temperature; n is the experimental exponent for the system of similar bodies under consideration.

When dealing with ideal gases, the first factor in the above equation can be neglected, since it does not vary greatly from one gas to another. Under these conditions the film thickness becomes

$$B = K_1 D \left[\nu/(\alpha g \Delta t)^{1/2} D^{3/2}\right]^n \text{ cm}.$$

It might be of interest to note here that the equation derived by Davis cited above gives exactly the same result for ideal gases as the one for B given here by Rice. For liquids and imperfect gases, however, Davis' method obtains a very different result and one which does not fit experimental data satisfactorily.

For the free convection from a long horizontal cylinder in gases and liquids, Rice finds the convection loss of heat to be given by the expression

$$W_c = 2\pi L \Delta\Phi / \log e\,(2B+D)/D \text{ watts}$$

Here L is the length of the cylinder in *cm*; $\Delta\phi$ is the thermal conduction in watts per *cm*; D is the diameter of the cylinder in *cm*; and B is the film thickness in *cm* from the equation for B above. It has been found that a sufficiently close approximation can usually be obtained by taking $n = 1/2$, $K = 2.12$ and $m = 1/4$ in the above equation for B.

For a *long vertical cylinder* in *gases*, the meagre data available give $n = 2/3$ and $K = 8.65$. For spheres in gases we have

$$W_c = 2\pi \Delta\Phi / \left[1/D - 1/(2B+D)\right] \text{watts}$$

where $n = 1/2$ and $K = 2.02$ in the equation for B.

For large surfaces where the area of the film is large compared with its thickness, the shape factor takes upon a very simple form $S = \frac{A}{B}$, and for moderate temperature differences, we may write $\Delta\phi = k_{av}\Delta t$. Under these conditions, the general expression becomes

$$W_c = (A k \Delta t / KD)\,(\mu C_p/k)^m \left[(\alpha g \Delta t)^{1/2} D^{3/2}/\nu\right]^n \text{ watts}$$

in which the terms with an exponent m reduces to unity for ideal gases.

For a *large long horizontal cylinder* in gases and liquids we take $K = 2.12$, $n = 1/2$, and $m = 1/4$ in the last equation. This equation for convection in air becomes

$$W_c = 0.000785 A (1/D)^{1/4} \rho^{1/2} (1/T_{av})^{0.123} \Delta t^{5/4} \text{ watts}$$

A is the area in square cm; D is the diameter of the cylinder in cm; L is its length in *cm*; p is the absolute air pressure in atmospheres; T is the average of cylinder and ambient absolute temperature in °Kelvin; and Δt is the temperature difference °C.

For a *large vertical cylinder* in *gases* we take $n=2/3$ and $K=8.65$, and then we have the equation for air as the medium.

$$W_c=0.00166A\,p^{2/3}(1/T_{av})^{0.415}\Delta t^{4/3} \text{ watts}$$

For *large spheres* in *gases*, $n=1/2$ and $K=2.0$ which results in an approximate convection loss in air of

$$W_c=0.00088A\,(1/D)^{1/4}p^{1/2}(1/T_{av})^{0.123}\,\Delta t^{5/4} \text{ watts}$$

For a *long thin vertical plane* surface, such as a ribbon in gases, we may assume as an approximation $n=1/2$ and $K=1.46$, and take D equal to the vertical height H. This will give for air

$$W_c=.00121A\left(\frac{1}{H}\right)^{\frac{1}{4}}p^{\frac{1}{2}}\left(\frac{1}{T_{av}}\right)^{0.123}(\Delta t)^{5/4} \text{ watts.}$$

It is shown in the general theory, that free convection tests will only give approximate values of the heat conductivity of the fluids and are only useful when an idea of the value is already available.

FORCED CONVECTION

In considering the transfer of heat by forced convection, Rice[6] has obtained very useful results. He has shown the effective film thickness, as obtained by the method of dimensions, to be given by the expression

$$B = K_0D\left(\frac{k}{\mu C_p}\right)^{\beta}\left(\frac{\mu}{\rho DV}\right)^{\alpha} \text{ where } K_0 \text{ is}$$

an experimental constant depending on the system of similar bodies under consideration; D is the characteristic linear dimensions of the body in *cms*; k is the heat conductivity of the film at its average temperature, in watts per cm per °C; μ is the viscosity at the same average temperature; C_p is the specific heat at constant pressure; β and α are experimental constants; ρ is the density of the fluid; and V is the mean velocity of the fluid relative to the surface. This expression reduces to a very simple expression for ideal gases for which the first factor becomes very nearly equal to unity and can be taken as such.

[6] Ind. & Eng. Chem. *16*, No. 5, p. 454; 1924.

For thin films and moderate temperature differences, the convection loss for *gases* and *liquids* becomes

$$W_c = (A\,k\Delta t/K_0 D)\left(\frac{\mu C_p}{k}\right)^{\beta}\left(\frac{\rho DV}{\mu}\right)^{a} \text{ watts},$$

in which the factor having the exponent β reduces to unity for ideal gases. The same expression with this term placed equal to unity will give approximate values for actual gases as has been shown in Rice's early work. When considering smooth pipes and a velocity of the fluid well above the critical, the available data in gases and liquids are satisfied approximately by taking $\beta = 1/2$, $a = 5/6$ and $K_0 = 60$.

In considering the relation between mechanical resistance and heat transfer, Rice has shown

$$W_c = (A\,k\Delta t\; R/v\mu)\left(\frac{\mu C_p}{k}\right)^{\beta} \text{ watts}$$

where R is the mechanical resistance in dynes per cm^{-2}. This last equation may be written in the form

$$W_c = \left(\frac{AC_p\Delta tR}{V}\right)\left(\frac{k}{\mu C_p}\right)^{1-\beta}$$

which conforms to Reynolds law as given by Stanton.[7] If the equation developed by Lees[8] for the resistance to flow in *smooth pipes* is substituted in the last equation and if we assume $\beta = 1/2$ we obtain for gases and liquids

$$W_c = \left(\frac{k}{\mu C_p}\right)^{1/2} A\rho C_p\Delta t\left[0.0009 + \frac{0.0763}{\left(\frac{VD\rho}{\mu}\right)^{0.35}}\right] \text{ watts}$$

This equation takes into account the variation of resistance with the degree of turbulency and should apply for all velocities above the critical velocity. For ideal gases this equation would reduce to

$$W_c = 1.16A\rho C_p V\Delta t\left[0.0009 + \frac{0.0763}{\left(\frac{VD\rho}{\mu}\right)^{0.35}}\right]$$

This equation reduces to the following for *air*

$$W_c = \left(0.417\frac{Ap v\Delta t}{T_{av}}\right)\left[0.0009 + \frac{0.0012\,T^{0.615}}{(vD\rho)^{0.35}}\right] \text{ watts}$$

[7] Technical Report Advisory Committee for Aeronautics (Great Britain) 1916-1917 pp. 16-31.

[8] Proc. Roy. Soc. *91*, p. 46; 1915-1916.

In considering rough pipes we will assume $\alpha = 1$, $\beta = 1/2$ and $K_0 = 136$. This will give us for *ideal gases*

$$W_c = 0.00635 \left(\frac{A\rho v k \Delta t}{\mu}\right) \text{ watts}$$

and for *air*

$$W_c = 0.0031 \left(\frac{A p v \Delta t}{T_{av}}\right) \text{ watts}$$

For a cylinder in *ideal gases*, we take $\alpha = 1/2$, and $K = 2.2$ and find

$$W_c = \left(\frac{A k\ \Delta t}{2.2\ D}\right) \left(\frac{\rho D v}{\mu}\right)^{1/2} \text{ watts}$$

This expression reduces for *air* to

$$W_c = 0.0018 L \sqrt{pDv}\ \frac{\Delta t}{T_{av}^{0.123}} \text{ watts}$$

Where L is the length of the cylinder.

In considering the heat transfer from *large smooth* surfaces, and for approximate calculations, we can take $\alpha = 1$, $\beta = 1/2$ and $K = 350$ which gives for *ideal gases*

$$W_c = 0.00246 \left(\frac{A\rho v k \Delta t}{\mu}\right) \text{ watts}$$

and for *air*

$$W_c = 0.0012 \left(\frac{A p v \Delta t}{T_{av}}\right) \text{ watts.}$$

For moderately rough surfaces we may apply the equations for *rough* pipes given above, and for very rough surfaces in ideal gases the relation $W_c = 0.010\ \frac{(A\rho v k \Delta t)}{\mu}$ watts.

It is found also that the heat transfer in mixtures is covered by the same general equations that apply to liquids and gases. For mixtures of a heavy with a light gas, the forced convection at high velocities over plane surfaces may be greater than in either gas alone. For example the complete expression $\left(\frac{\mu C_p}{k}\right)^{1/3} \left(\frac{k\rho}{\mu}\right)$ for high velocities reduces to $0.41\ \frac{p}{T_{av}}$ for air; and for hydrogen $0.40 \left(\frac{p}{T_{av}}\right)$; whereas for 95 per cent hydrogen and 5 per cent nitrogen this reduces to $0.45 \left(\frac{p}{T_{av}}\right)$. This means that for high velocities, the convection loss is the same in air as it is in

pure hydrogen, but it is 13 per cent greater in commercial hydrogen (95 per cent hydrogen and 5 per cent nitrogen) than in either pure hydrogen or air.

CONCLUSIONS

It is quite evident from the above discussion, that the working out of the exact relations by means of which the heat losses by convection can be calculated for various conditions, depends upon the accuracy of the experimental data. All possible essential precautions should be made to obtain accurate data of all factors to be considered in connection with heat losses by convection. More care should be given, in particular, to the determinations of the temperature of the surface of the medium from which the heat is being convected. At the present time, the exact determination of surface temperatures is by no means thoroughly worked out, and consequently more study should be made along this line. It is desirable also that we obtain the radiation constants for a large variety of materials and surfaces, in order that we can determine with more exactness the radiation losses involved when considering the heat losses by convection.

In considering the total heat loss when forced convection is involved, the loss by radiation plays a rather unimportant part. Such is by no means the case for free convection, and for this reason an exact knowledge of the methods of accurately determining surface temperatures and the radiation constants would be very helpful. In conclusion, it is doubtless desirable to state that the equations quoted and referred to in this discussion are not to be considered as final solutions for the cases involved. While they do give fairly good agreement with experimental data, as further data become available, it will be possible to develop more exact solutions for the various cases involved.

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THE USE OF THE ELECTRON TUBE PEAK VOLTMETER FOR THE MEASUREMENT OF MODULATION*

By C. B. Jolliffe

Methods of measuring the degree of modulation of a radio-frequency generating set have been described[1] by Nelson and Conrad but both systems have the disadvantage that they measure the amplitude of the audio-frequency current before it is impressed on the radio-frequency current. The oscillograph has been used extensively and provides an ideal method of measuring the degree of modulation but it is an expensive instrument and not readily portable.

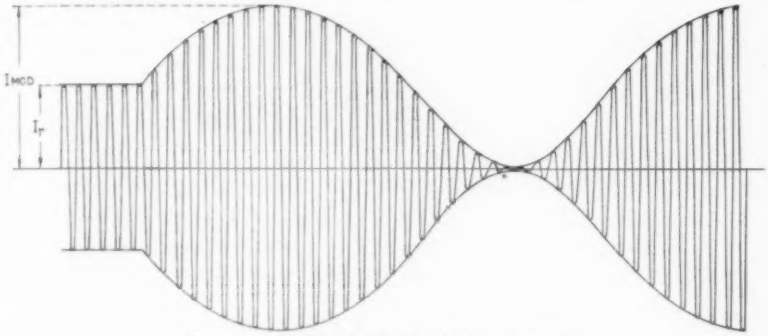

Fig. 1. *Sine modulated radio frequency current.*

The electron tube peak voltmeter described by van der Bijl[2] may be used as a means of measuring the modulation of a radio-frequency current whose maximum value for complete modulation varies between the limits zero and two times the maximum value of the unmodulated radio-frequency current (See Fig. 1). Such a current is produced by the so-called "Heising" or "constant current" system of modulation. In brief, if the peak value of the radio-frequency current is measured without modulation and then the modulation is applied and the peak value again measured the ratio

$$\frac{(I_{MOD}-I_r)\times 100}{I_r} = \text{per cent modulation} \qquad (1)$$

* Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce.

[1] Nelson, U. S. Patent 1,478,050. Conrad, U. S. Patent 1,477,316.

[2] van der Bijl. Thermionic Vacuum Tubes, p. 367.

I_{MOD} = peak value of the modulated current.
I_r = peak value of the unmodulated radio-frequency current.

The actual apparatus needed is shown in Fig. 2. The current I flows through the resistance R (1000 Ω) so that measurements on the variation of the voltage across the fixed resistance R gives values which are proportional to the variation in that current. The current I is proportional to the output current of the radio-frequency generating set.

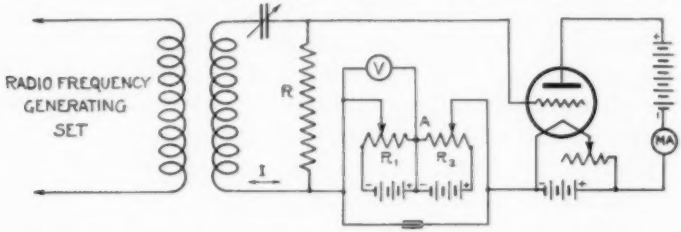

FIG. 2. *Electron tube peak voltmeter used to measure percentage modulation.*

The principle of the voltmeter is that the voltage of the grid is adjusted until the milliammeter just fails to show a plate current. The resistance R_2 (0 − 2000 Ω) with R_1 (0 − 100 Ω) set at zero (A) is adjusted until the plate milliammeter reads zero. The unmodulated radio frequency is then applied and R_1 adjusted until the milliammeter again reads zero. The voltmeter V gives then the peak value of the radio-

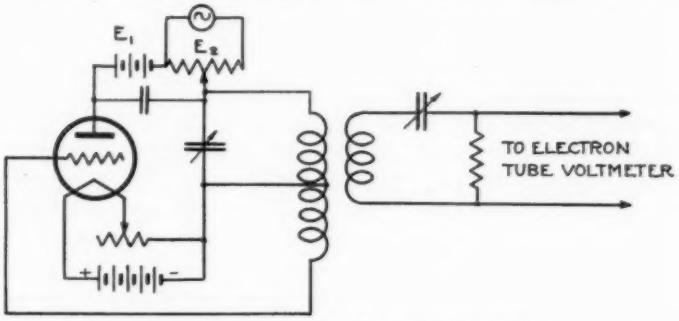

FIG. 3. *Generating circuit used to test method.*

frequency voltage which is proportional to the current I_r. The radio frequency is then modulated and R_1 further increased until the plate milliammeter again reads zero. The voltmeter will then read the peak value of the modulated radio frequency voltage which is proportional to I_{MOD}. The percentage modulation then follows from Equation (1).

To test this method the generating circuit shown in Fig. 3 was used. The variation of output current with plate voltage for this circuit is shown in Fig. 4. Since, for the upper portion of the curve the output current is proportional to the plate voltage, the degree of upward modulation may be calculated from the measured values of E_1 and E_2. E_2 was either a 500 or 60-cycle sinusoidal alternating current source having an effective voltage of 120 volts. E_1 is a direct current source and may be made any value.

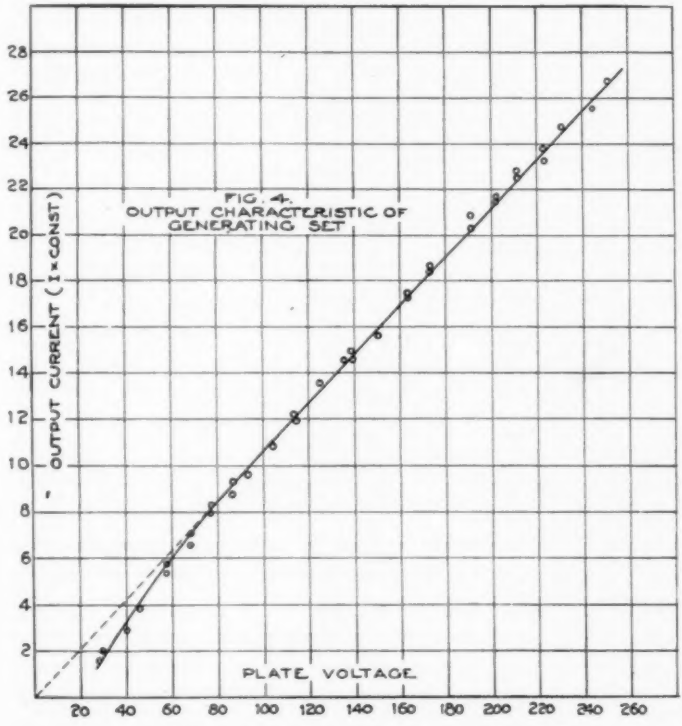

FIG. 4. *Output characteristic of generating set.*

The following table gives sample data on the values of the per cent modulation calculated and measured. This table shows that the accuracy of the measurement as made was not greater than about 4 per cent. The method, however, is sufficiently accurate for many purposes.

It has proved very useful in making quantitative measurements of the percentage modulation in connection with measurements on electron tube properties which involve the degree of modulation. It could be used in a system to indicate continuously the limits of modulation in a radio telephone transmitting station. The circuit could be coupled to the transmitting set and the resistance R_1 adjusted so that with no modulation the plate milliammeter reads zero. When the current is modulated then the milliammeter would show a deflection which could be calibrated in terms of per cent modulation. The modulation

TABLE I.

E_1	E_2 Eff.	I_r	I_{MOD}	$I_{MOD}-I_r$	Measured Value $\frac{I_{MOD}-I_r}{I_r}$	Calculated Value $\frac{E_2\times 1.41}{E_1}$
Modulation frequency = 500 cycles						
120	85	14.3	29.1	14.9	1.05	1.00
147	85	17.8	32.2	14.4	.81	.82
185	85	23.8	38.1	14.3	.60	.64
Modulation frequency = 60 cycles						
135	96	15.5	31.0	15.5	1.00	1.00
135	90	15.9	31.1	15.2	.96	.94
	80	15.8	28.8	13.	.82	.83
	60	15.9	25.7	9.8	.62	.62
	50	15.9	24.	8.1	.51	.52
	40	15.9	22.1	6.2	.39	.42
154	60	18.2	27.8	9.6	.53	.55
142	50	16.4	24.3	7.9	.48	.50
126	85	14.3	28.3	14.0	.98	.96
Radio frequency = 470 kilocycles						

then could be kept adjusted so that the milliammeter reads the degree desired. The instrument could be used at any time to measure the exact degree of modulation.

This method gives a fairly accurate measure of the degree of upward modulation. It can not, however, give any indication of the characteristic of the current when the modulation is downward. It is believed that it is superior to other simple methods of measuring modulation.

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THE GRANULAR RESISTOR FURNACE*

By O. P. Watts

USES

The granular resistor furnace is useful for heating tubes and crucibles to temperatures attainable only by the electric furnace, and where greater uniformity of heat is required than can be obtained by an arc. It is a most convenient method of melting metals and alloys in amounts of 100 to 1000 grams, and for carrying out high temperature reactions on a small scale.

CONSTRUCTION

On a fireproof table or floor, a layer of firebrick is supported on other bricks laid on edge, so that there are channels for air cooling. On this is laid a layer of magnesia brick of the length and width of the furance desired; a row of the same bricks is laid on edge to form the sides of a rectangular box, with the ends left open for insertion of electrodes. Firebrick are now laid along the sides to hold the magnesia brick in place, and carbon electrodes, preferably rectangular, are inserted in the ends. If crucibles are to be lifted from the furnace for pouring the metal, the channel should be about 3/4″ wider than the largest crucible used, but the area of cross section of the furnace should be kept as small as possible to lessen the current required, and the crucibles should be set about 2″ apart lengthwise of the furnace. If the charges are to be allowed to cool in the furnace, the crucibles may be set an inch apart lengthwise, and several rows may be placed in the furnace if desired. If the electrodes that lead current into the furnace are much smaller than the resistor, a "spreader" of carbon or graphite should be placed across the interior end of the electrode so that the current will spread uniformly in the resistor, instead of passing only through that portion immediately in front of the electrodes.

CRUCIBLES

For low temperatures fireclay or black-lead crucibles may be used, but for melting pure iron and other high temperature processes these are destroyed by the reducing action of the hot carbon, and only

* One of a series of reports prepared at the request of the Committee on Research Methods and Technique appointed by the Division of Physical Sciences of the National Research Council. It is the purpose of these reports to present in brief outline a summary, more or less critical, of the methods which may be employed in various kinds of Physical measurements. See Editorial in this Journal *9*, p. 410, 1924.

crucibles machined from graphite electrodes are suitable. For metals which take up carbon when melted, graphite crucibles must be lined with magnesia. This should be calcined as strongly as possible, or better fused in the electric arc, crushed, and ground to a fine powder, which is dampened with water and tamped into the crucible around a form of wood, which is then withdrawn. The crucible and lining are dried slowly for 8 to 10 hours, placed in the furnace, covered with a graphite lid cut from an electrode of the same size as the crucible, completely covered with resistor carbon, and heated for 1 to 2 hours at a maximum temperature of 2000°C, and allowed to cool in the furnace over night. The linings should be stone-like in appearance. They may be used in the crucible in which baked, or removed and stored for future use in similar crucibles, but cannot be used without the protective case of graphite, as when white-hot magnesia has too little strength to stand handling.

Graphite crucibles tend to short-circuit the resistor, and hence develop a hot spot where current enters the crucible; they are, however, such good conductors of heat that this rarely does any harm. If the crucible is an insulator, the hottest spots are on its sides, where the cross section of the resistor is least, and since such crucibles are poor heat-conductors, it may be necessary to arrange for a uniform thickness of resistor on all sides of the crucible.

THE RESISTOR

Granular carbon or graphite may be used, but the latter has the disadvantage of a low resistivity which necessitates a much greater amperage to heat the furnace in which it is used. Resistor may be bought of any manufacturer of carbon electrodes, or may be made from coke or scraps of carbon or graphite electrodes by crushing and screening. For particles of fairly uniform size the finer the particle the higher the resistance. Dust lowers resistance by filling the voids, so that where the amperage is limited it is well to screen the resistor after using it a few times. For small furnaces the resistor should be finer than for large ones. Through 12 mesh and held on 20 is a convenient size for laboratory furnaces. When especially high resistance is desired carborundum may be added to the carbon.

VOLTAGE AND POWER REQUIREMENTS

Because of the large negative temperature coefficient of granular carbon, voltage regulation from 110 to 40, in steps of 20 to 30 volts, is desirable. The desired regulation is simply secured by having several

points of connection to an auto-transformer, or to the secondary of a standard transformer, and changing one furnace cable from one to another of these when it is desired to raise or lower the power input.

For rapid heating of a furnace 20″ long, 3 1/2″ wide and 7″ deep for melting pure iron in three crucibles 3″ in diam. and 6″ high, 40 to 60 K.W. is desirable, although, by taking more time, a maximum of 40 K.W. would suffice. In a furnace 53″×12″×9″ deep, 36 crucibles each 3″ in diam. and 6″ high have been heated hot enough to melt electrolytic iron in six hours with an average of 50 K.W. and a maximum of 70 K.W. for moments. The metal was not poured, but left to cool in the furnace, and the crucibles were completely buried in the resistor in this case.

OPERATION

The crucibles are placed in the furnace as already specified, covered with Acheson graphite covers if they are to be completely buried, or with pieces of magnesia brick or fireclay if the metal is to be poured into molds. The resistor is then poured in to the desired depth, and left to lie loosely, except where it makes contact with the electrodes, at which point it may be tamped. Should the furnace fail to heat rapidly enough at the maximum voltage, magnesia bricks may be laid on the ends of the resistor and pressed down; as a last resort the resistor may be tamped between the crucibles.

Care should be taken that the furnace does not heat too rapidly, for there is a tendency for current to flow in the lower part of the resistor where pressure is greatest, and this may become so hot that the bottoms of the magnesia linings are destroyed before warning is given by looking at the top of the furnace. Rapid reduction of magnesia by carbon begins at 2030°C.[1]

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[1] D. S. Grenfell. Tr. Amer. Electrochem. S. *27*, 231.

Glow Discharge subjected to Magnetic Field.—This is chiefly a description of the appearance of an unusually arranged glow discharge under magnetic field. A cylindrical tube 4 cm in diameter and 28 cm long was half-filled with mercury, laid on its side, and the discharge maintained in rarefied gas between the mercury surface as cathode and a vertical wire as anode. This arrangement was devised partly to keep the cathode cool and partly to minimize the influence of the walls. The magnetic field (strengths up to 1200 gauss) was applied horizontally, e. i. parallel to the surface of the mercury and perpendicular to the axis of the tube. Under its influence the glow discharge, normally overlying a circular patch on the mercury underneath the anode wire, spreads out laterally, along the axis of the tube, into a "long, straight strip, beginning under the anode, with astonishingly sharp lateral boundaries." When the current was large there were two or even four narrow, sharply defined parallel strips. The thickness of the cathode dark space was measured; it is in general reduced by the magnetic field, there being a minimum value about 0.7 mm which it approaches as the field is indefinitely increased. (If the pressure is so high that the cathode dark space is initially narrower than this, magnetic field has no visible effect.) The current-density (quotient of current by area of glow) seems to vary about as the inverse square of the thickness of the cathode dark space, but it is uncertain whether the definition really means anything. About all that can be concluded from the configuration of the discharge is that the electrons describe their long cycloidal paths in the plane normal to the magnetic field without being thrown out of that plane by collisions. [A. Günther-Schulze, Reichsanstalt; ZS. f. Phys. *24*, pp. 140-147, 1924.] K. K. DARROW

Explanation of Abnormal Low Voltage Arcs.—In argon at 2 mm pressure an arc with no oscillations was maintained at 4 volts P. D. between a hot cathode and an Ni anode 1 cm apart; an exploring electrode consisting of 1-mil wire projecting 3 mm from a glass stem was moved about in the arc. It was "used according to Langmuir's recent method" with reference to the Nov. 1923 article in the G. E. R., but no further details are given. It was found that the gas near the filament was *about 11.5 volts above the filament*, and "there was an electric field in the direction reverse to the applied field throughout most of the space between anode and cathode." Furthermore "the concentration of ions, either positive or negative, was found to decrease from about $100 \cdot 10^{10}$ per cc near the cathode to about $2 \cdot 10^{10}$ per cc near the anode. The average kinetic energy of the electrons outside the region of the cathode drop was found to vary from 2 to 4 volts. Analogous results were found in a Hg arc operating at about 3.5 volts." Also "it is easily shown that the number of ions of either sign is at least a million times greater than the excess of one kind over the other except in the region of the cathode drop." [K. T. Compton and C. H. Eckart; Princeton; Nature, *114*, p. 51, 1924.] K. K. DARROW

A METHOD OF PRODUCING SHORT WAVE LENGTH OSCILLATIONS IN ELECTRON TUBES

By G. Breit

1. A description of a short wave-length oscillation in an electron tube having singular properties has been given by the writer.[1] The oscillation takes place in a three electrode tube having a cylindrical structure, the filament and grid being helical and bifilarly wound while the plate is co-axial with the filament and grid. The negative pole of a battery is connected to the filament and the positive through a resistance to the grid. The plate is left disconnected. Oscillations take place when the filament temperature has the proper value. In the writer's note referred to above the oscillations were detected by means of a crystal detector and galvanometer and their wave-lengths have been ascertained to be either in the neighborhood of 60 cm or in that of 150 cm. At the time of writing the above note the nature of the oscillations was not definitely explained. Additional data has been taken since and the results show that a distinct space charge effect is connected with the oscillations and that further it has many features in common with the oscillations of Barkhausen and Kurz,[2] though on account of a different structure and different operating conditions some other properties appear in the tube here studied.

In order to make the observations of oscillations depend on other things than the coupling to the crystal detector the charging up of the plate was used. A C.T.R. Wilson tilted electroscope was connected between the filament and the plate. In the absence of oscillations the plate takes up a potential nearly equal to that of the filament which varies only slowly with the emission (changes in the resistance of insulating parts of the tube and perhaps contact differences of potential are probably the main effects). If, however, the oscillations start, the plate acquires a negative potential with respect to the filament, which disappears when the region of oscillation is past. The deflection of the fibre of the electroscope is practically instantaneous and battery drifts could be eliminated by this method much more effectively than by the use of the crystal detector.

[1] A singular Case of Electron Tube Oscillations. Journal Franklin Institute, *197*, p. 355; 1924.

[2] Phys. Sz. *21*, p. 1; 1920.

The phenomenon of the charging of the plate under similar circumstances has been first observed by Barkhausen and Kurz (l.c.) and the explanation of the phenomenon is found in their paper.

The fact that the potential of the plate returns to the normal level after the temperature of the filament becomes too high and that in many cases two or three ranges of filament emission have been observed in which the plate becomes charged indicate strongly that the charging of the plate is a reliable indication of the presence of oscillations and that the dependence of the plate potential V_P on grid current I_G does not owe its particular form to some secondary influence. This is further supported by the fact that in many cases the V_P, I_G curve has been found to be reversible at the end of large values of I_G (See Fig. 7) and that discontinuous drops in V_P occur within the oscillation range. Direct measurements with the crystal detector however show the presence of oscillations only over a part of the range indicated by the electroscope (See Fig. 2) as compared to Fig. 1. Sudden and discontinuous changes taking place in the detector curve usually at the same time with the sudden changes in the V_P, I_G curve.

In order to investigate the oscillations in the region where the crystal detector fails a small radio receiving tube (Type W D 11) was employed as a detector of the Hertzian waves. The connections were the standard connections of radio the grid and filament being connected by a short turn of wire and a galvanometer being put in the plate circuit instead of telephones. (The large dc plate current being balanced out by means of auxiliary battery and a suitable potentiometer arrangement.) By using in the filament circuit a set of four good rheostats connected in parallel in pairs and the two pairs being connected in series sufficient steadiness was obtained to be able to use a wall galvanometer. By this means oscillations were detected where they could not be found by the crystal. The writer is not prepared to maintain that oscillations could be detected in all of the range by this means. However, he has seen cases where only the mode of the oscillation changed, the deflections of the electroscope and of the galvanometer being changed discontinuously and not at all in proportion. This together with the evidence previously cited makes it feasible to suppose that oscillations are present throughout all of the range in which the plate carries a negative charge and that this charge can be taken as an indication of the oscillations. Many observations of V_P against I_G have been made and some of the most typical ones are reproduced and discussed below.

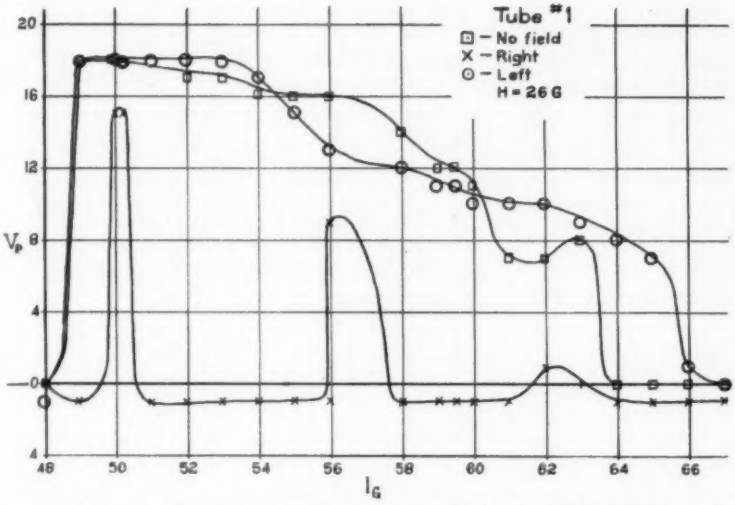

FIG. 1a. *Effect of magnetic field on oscillation characteristic when the field is applied successively in opposite directions.*

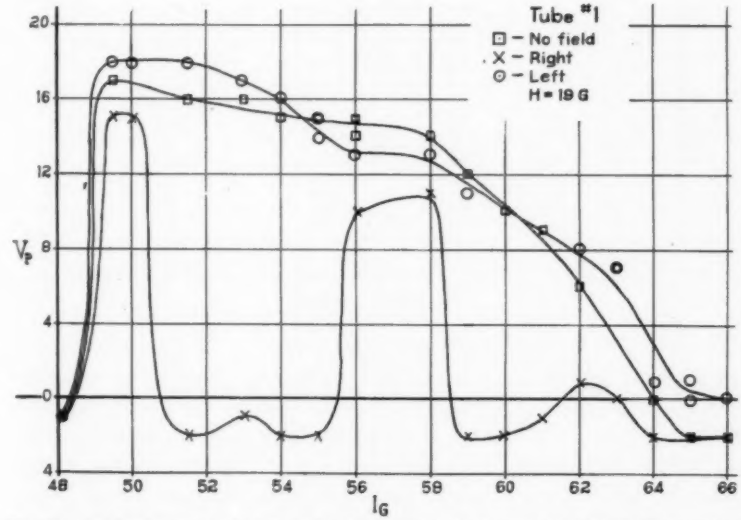

FIG. 1b. *Effect of magnetic field on oscil ation ch racteristic when the field is applied successively in opposite directions.*

2. Figs. 1*a*, 1*b*, 1*c* show some of the earlier observations taken on Tube No. 1. These observations were taken by keeping the grid battery unchanged and varying the filament current by small steps. The tube was mounted vertically and it was put inside a coil wound on a pasteboard cylinder with axis vertical. At each step a reading of the electroscope was taken with the field off and with the field on in either direction. The squares give readings in the absence of the field. The circles correspond to one direction of the field and the crosses to the opposite. The three curves correspond to 9, 19, 26 gausses respectively. The influence of the magnetic field is very pronounced.

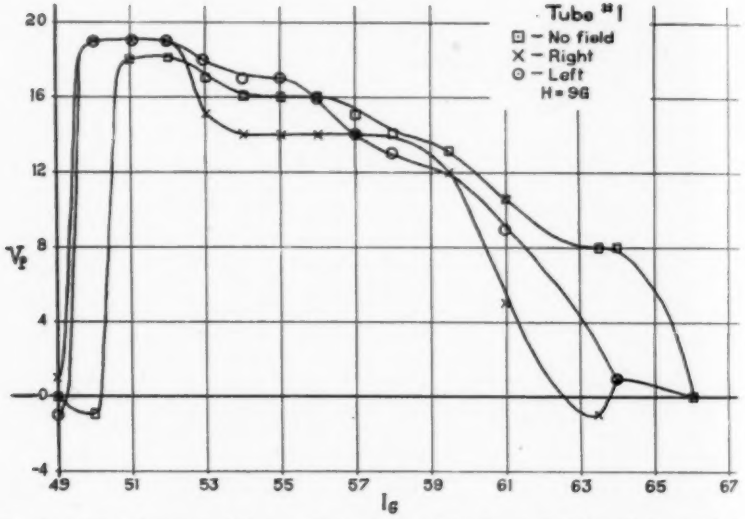

FIG. 1*c*. *Effect of magnetic field on oscillation characteristic when the field is applied successively in opposite directions.*

It was soon found that observations taken by this routine involve several complicating factors. Thus, the curve in the absence of a field is affected by the fact that the field has been applied and removed intermittently. In other words, the tube shows a hysteresis and the changes of magnetic field produce irreversible changes in the state of oscillation. This may be seen on Fig. 3*a*. Here the filament current (and consequently also I_a) has been first increased in the absence of a magnetic field (except that of the earth). These points are plotted as squares. It has then been decreased again in the absence of a field. These points

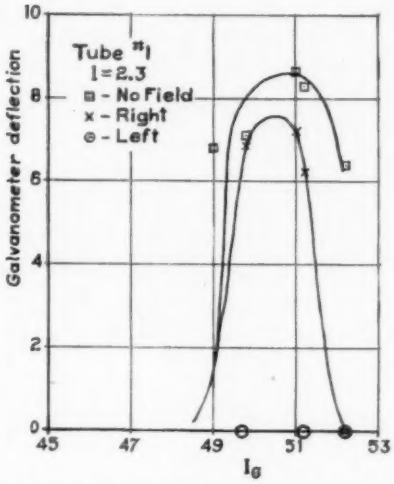

FIG. 2. *Galvanometer deflections with and without field.*

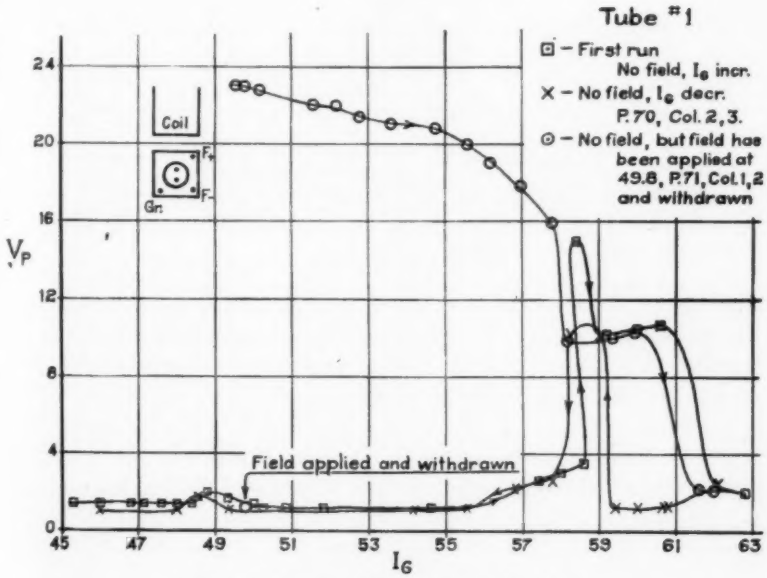

FIG. 3a. *Fatigue and jerk up effect for tube No. 1.*

are plotted as crosses. I_G has then been increased again to 49.8 m.a. where a magnetic field was applied and withdrawn. This resulted in a discontinuous change of V_P. From there on I_G has been increased in the absence of a field giving the part of the curve marked by circles. A distinct hysteresis is thus present.

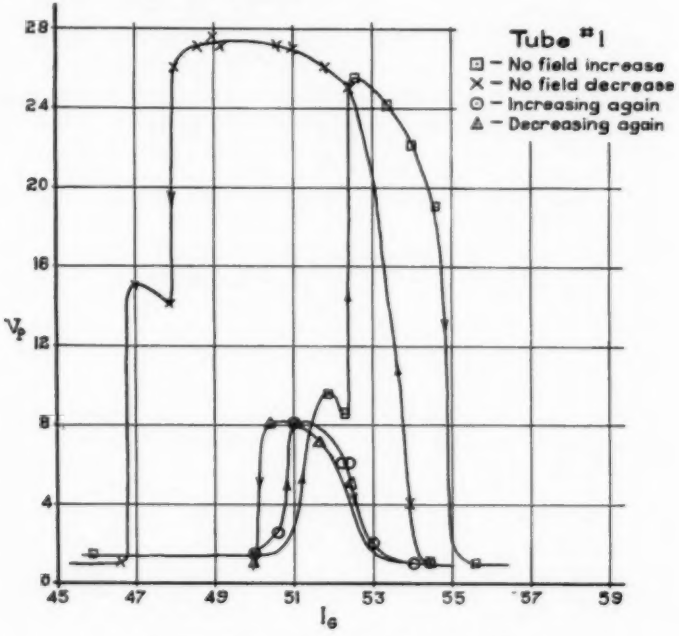

FIG. 3b. *Fatigue and jerk up effect for tube No. 1.*

When a tube is in constant use it is likely to show fatigue effects. These are shown on Fig. 3*b* which shows also the effect of interchanging the filament leads right at the tube. The squares and crosses give the normal curves corresponding to increasing and decreasing values of I_G respectively. The circles and triangles correspond to the fatigued tube. It is seen that the shape of the V_P, I_G curve depends strongly on the direction in which the filament current is passed. Care has been taken to ascertain that this is a true effect not connected with a different spacial position of the leads. Thus when the tube or the leads were moved around no appreciable difference having been found.

Figs. 4*a*, 4*b* show the dependence of V_P on I_G for another tube (No. 2). Only the earth's field is present here. As before the squares

correspond to increasing and the circles to decreasing I_G. The filament terminals are interchanged for 4*a*, 4*b*. The location of the terminals as well as the vertical plate supports being shown on the figure. It is seen that the up and down curves are likely to overlap or nearly so. The detailed structure of the curves is again seen to be different for the two choices of positive and negative connection to the filament and both of them differ very much from the corresponding curves for tube No. 1. This suggests that the detailed structure of the curves depends on the geometrical arrangement of the elements in the tube

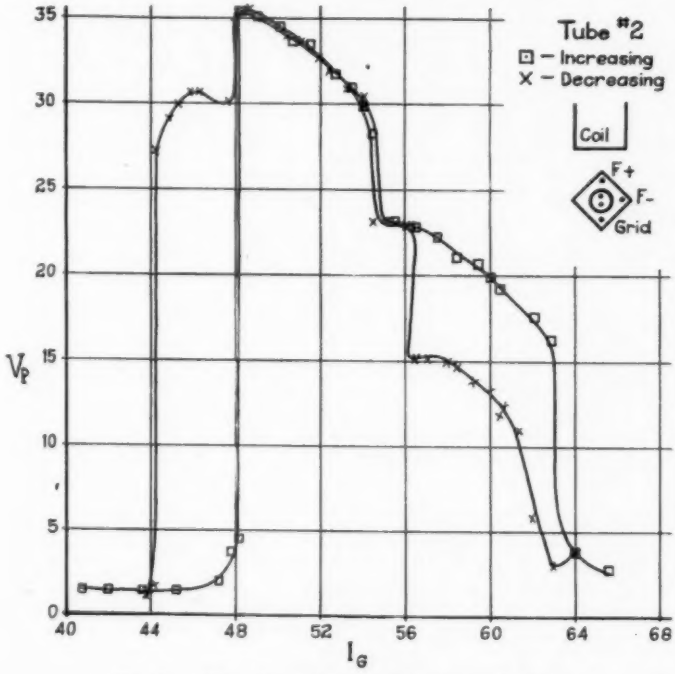

FIG. 4*a*. *Effect of reversing filament leads for tube No. 2.*

in a marked manner because the construction of the two tubes was intended to be the same. It appears therefore that oscillations first originate on account of the local peculiarities of the field at some one point or spire of the filament and a neighboring turn of the grid but that once this oscillation is started it is likely to help the oscillation to spread throughout all of the filament grid structure. The overlap-

ping portions of the up and down curves correspond then to the general state of oscillation.

A consequence of this supposition is that the tube must be susceptible to small deformations in the inside structure. These may be produced by inclining the tube. This actually produced a small but unmistakable change in the deflection of the electroscope, the change being reversed as one passed from an upward to a downward slope of the curve. This observation was made by watching the electroscope and tipping the tube by hand. Tipping in various azimuths gave the

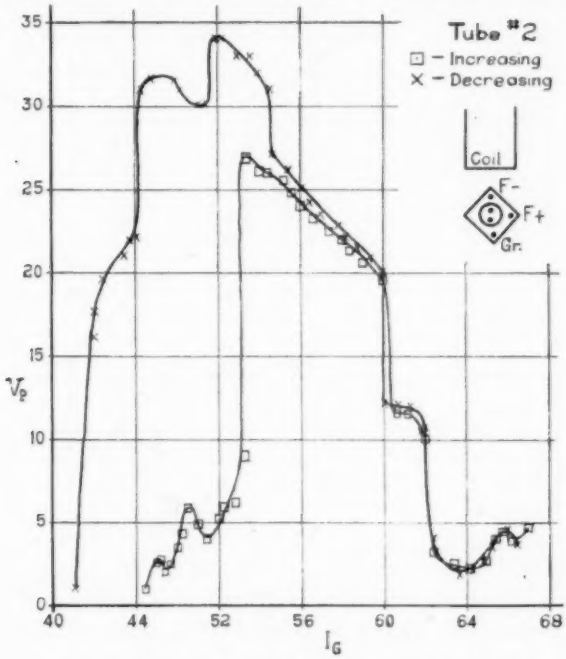

FIG. 4*b*. *Effect of reversing filament leads for tube No. 2.*

same effect showing that the earth's field was not operative and applied fields of the order of the earth's and neutralizing it also failed to give a readable effect. The influence of the tipping appears therefore to be mainly due to gravity. A change in the shape of the curves has been also observed with tube vertical and horizontal.

Figs. 5*a*, 5*b* show the effect of a small magnetic field which in this case is exceptionally large. On removing the field the hump marked

disappears, the curve becoming identical with 5a. Whether the hump is brought out on account of a mechanical displacement or on account of a critical influence of the magnetic field on the electronic stream the writer does not know. The first is probably the case.

Fig. 6 shows the influence of the application and withdrawal of a small magnetic field (3 gauss) in the case of tube No. 2, the tube having been very distinctly "jerked up" to the point marked and then coming down again to a minimum before starting on the next hump.

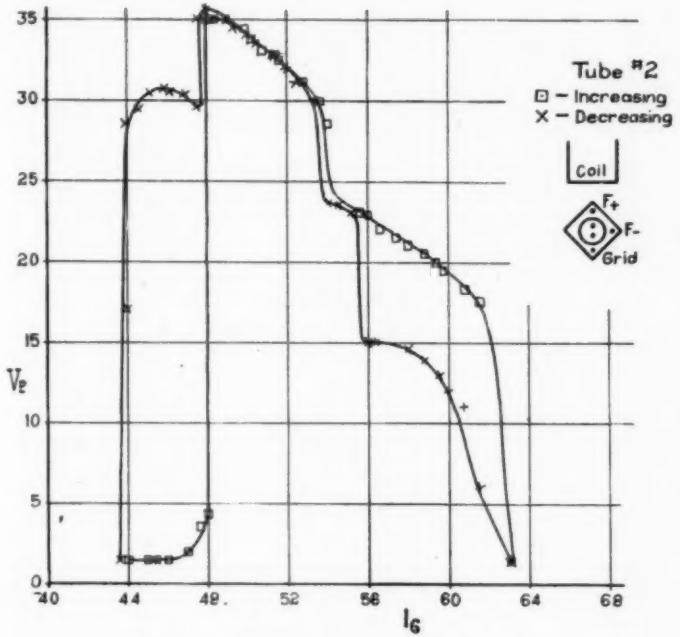

FIG. 5a. *Hump brought out by small magnetic field.*

Figs. 7*a*, 7*b* show the $V_P I_G$ relationship for tube No. 3 which is seen to be different from both No. 1 and No. 2. Fig. 7*b* was taken with an applied potential of 160 volts while the other curves were taken with 240 volts.

To summarize the above, the oscillations occur in the same general range of filament emission, the detailed relation of V_P to I_G depends on the particular tube and experiments with gravity and magnetic

field effects indicate that the oscillation conditions depend markedly on the relative positions of the fine turns of the filament and grid.[3]

3. On Fig. 8*a* the characteristic curves of grid current against grid potential are plotted for filament currents of 1.40, 1.45, 1.50 amp. respectively. The curves marked by circles and triangles give the dependence of V_G on I_G for the oscillation just starting in and just dying

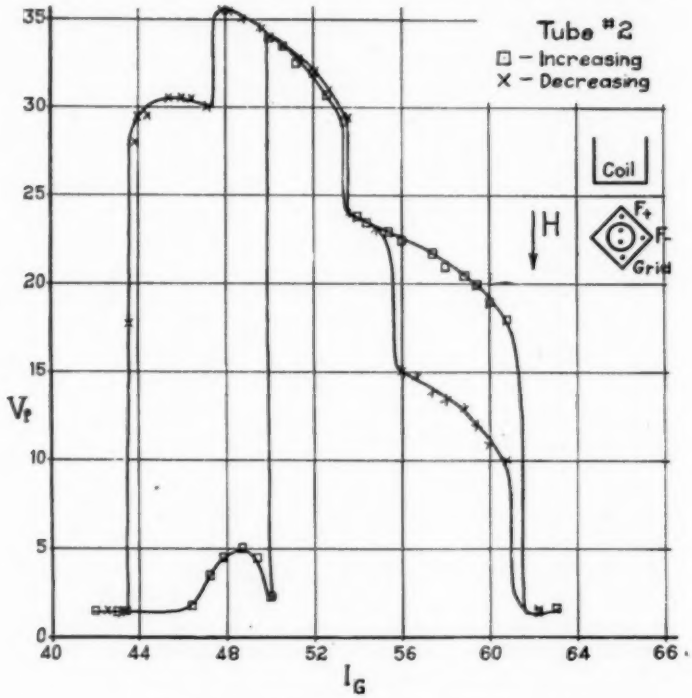

FIG. 5*b*. *Hump brought out by small magnetic field.*

off. It is seen that distinctly different filament temperatures are needed to produce the oscillations at different voltages. It also appears that both the circle and the triangle curves if prolonged would bear some relation to Langmuir's space charge curve and the oscillation occurs

[3] The order of the magnitude of the magnetic fields producing strong effects is such that the mechanical force due to it is roughly the probable force due to gravity. There appears to be no simple systematic dependence of the effects of the magnetic field on its direction, though some evidence of an azimuthal effect has been obtained.

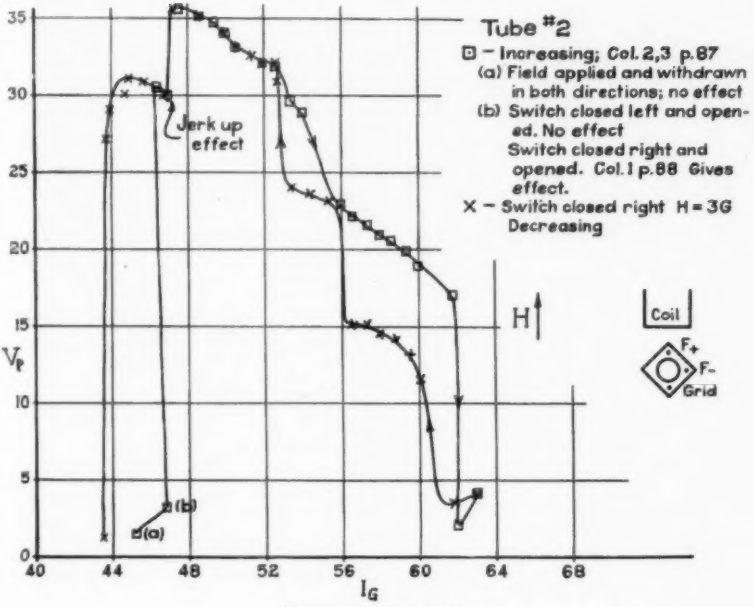

FIG. 6. *Jerk up effect.*

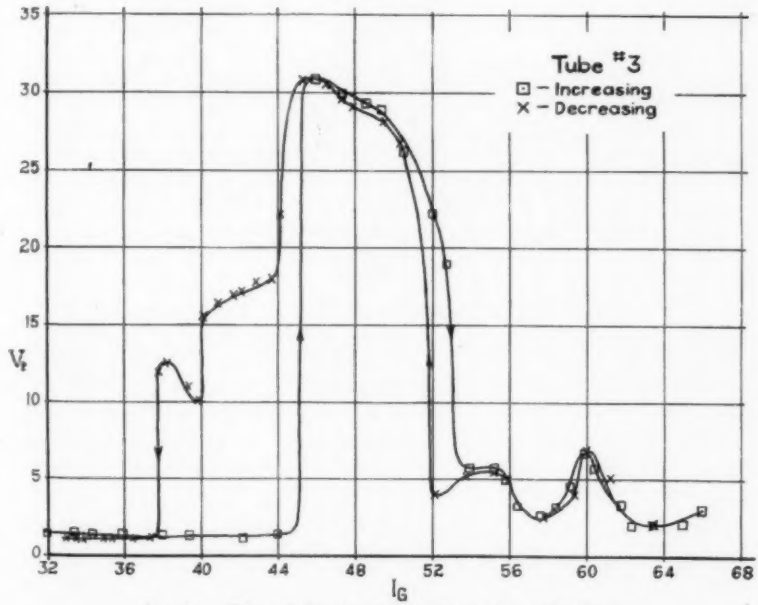

FIG. 7a. *Effect of changing applied potential for tube No. 3.*

in a region in which the space charge effect has a definite relation to the voltage applied.

Fig. 8*b* gives the relations between V_G and I_G for which the oscillation just begins for the three tubes. Tube No. 3 shows an interesting break in the curve showing this relationship at about 100 volts. This break was checked on two consecutive days the crosses referring to Feb. 10 and the circles to Feb. 11. In the same region tube No. 1 shows no such break. Tube No. 2 is seen to oscillate in a slightly

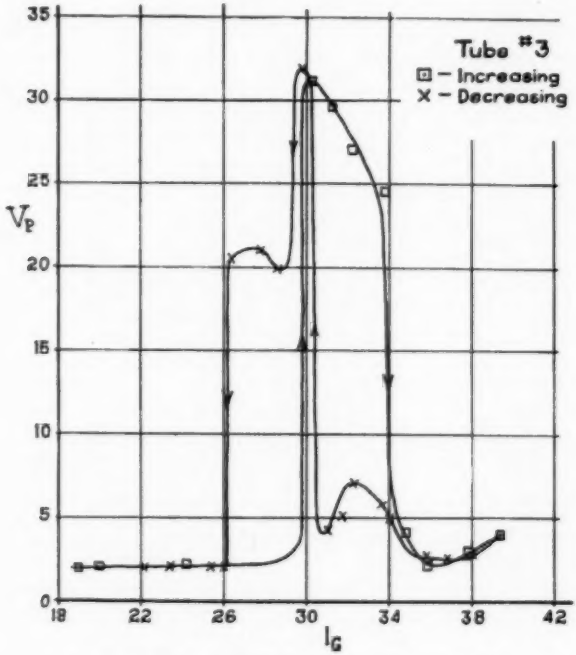

FIG. 7*b*. *Effect of changing applied potential for tube No. 3.*

different region. The oscillation corresponding to longer wave lengths is shown by the lower triangle curve for Tube No. 2. It is worth noting that tube No. 3 has been misused by someone who applied a too high voltage which flashed and blackened the seal. The break may perhaps be attributed to the influence of a slight amount of gas present in the tube.

The wave length of the oscillations has been measured. Changes in it appear however to take place very easily. This agrees with the observa-

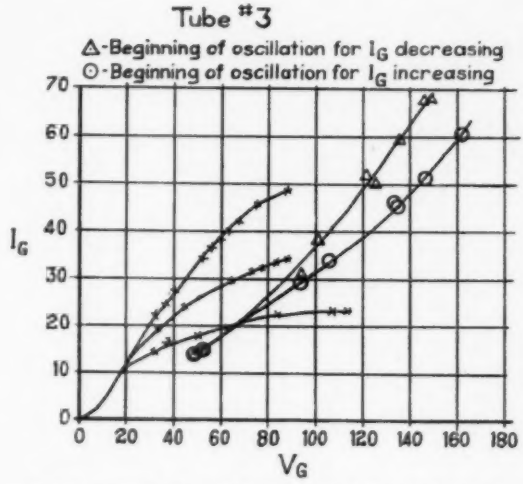

FIG. 8a. *Oscillation and static characteristic for tube No. 3.*

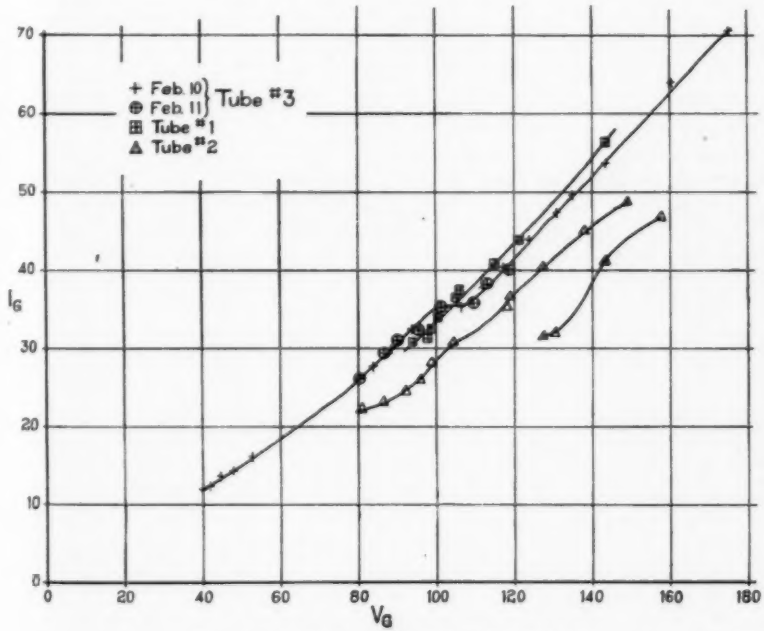

FIG. 8b. *Comparison of oscillation characteristics.*

tions of Scheibe[4] on Barkhausen Kurz oscillations in tubes not used on a pump.

The original contention of Barkhausen Kurz as to the necessity of having a strictly cylindrical tube structure has been since disproved by Schaefer and Merzkirsch[5] and by Scheibe[6] and it is therefore likely that the oscillations here described are not essentially different from those of Barkhausen and Kurz, though on account of a different structure of the tube they exhibit different properties.

SUMMARY

The oscillation previously described is studied further by investigating the negative potential to which the plate is charged. The oscillation is shown to depend critically on the exact position of the grid with respect to the filament and evidence is given for regarding the oscillation as first starting in one part of the tube and then spreading by steps through the whole structure. The relation of the oscillation range to the characteristic curves indicates an influence of space charge. Strong hysteresis effects with and without a magnetic field are observed.

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MINNEAPOLIS, MINN.

Energy Relations at the Cathode of the Glow Discharge.—A glow discharge was set going in rarefied gas between a wire anode and a large saucer of mercury as cathode; the rate of increase in the temperature of the mercury was measured over a period of ten minutes, during which it did not rise enough to affect the nature of the discharge appreciably; the correction for efflux of heat was made from the cooling curve in the usual manner; and the rate of absorption of heat by the cathode as thus deduced, compared with the product of current by voltage across the cathode fall. It was found that 80 per cent of the total electrical energy spent in hydrogen, 85 per cent of that spent in nitrogen and in water vapor, appeared as heat in the cathode. The pressures in these experiments ranged between 1.70 and 7.50 mm Hg; the data show no trend with pressure. [A. Günther-Schulze, Charlottenburg; ZS. f. Phys. *23*, pp. 334-336, 1924.]

K. K. DARROW

[4] Adolph Scheibe, Ann. d. Phys., *73*, p. 54; 1924.
[5] Schaefer and Merzkirsch, ZS. f. Phys., *13* (3) p. 166; 1923.
[6] Scheibe, 1. c.

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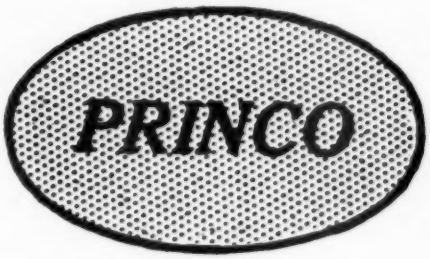

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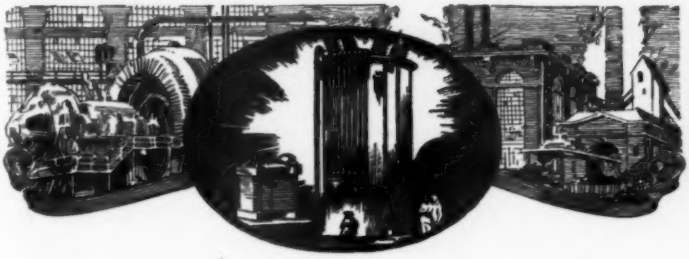

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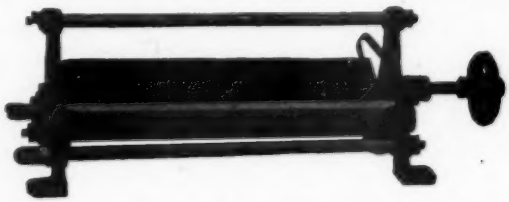

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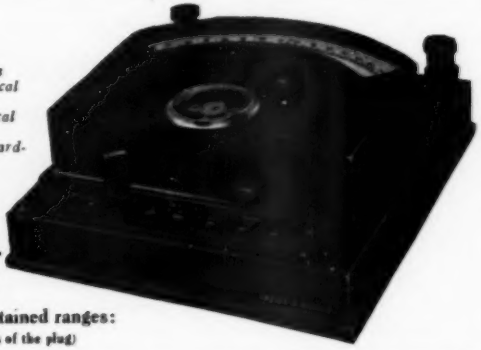

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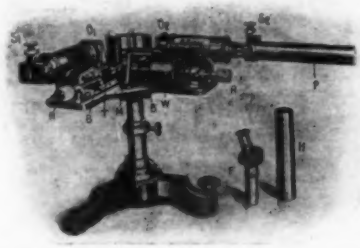

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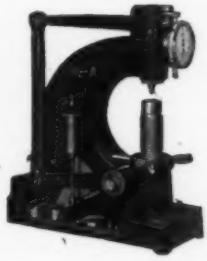

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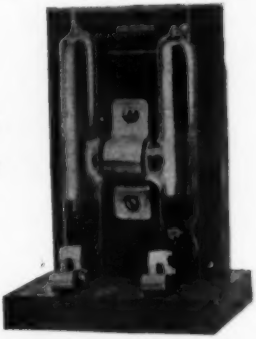

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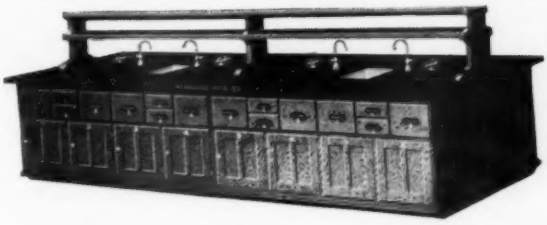

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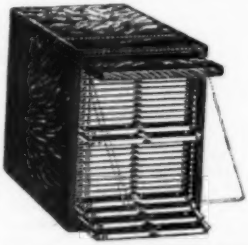

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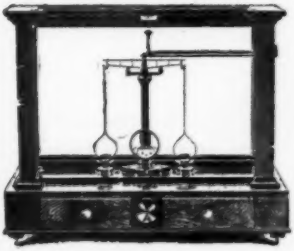

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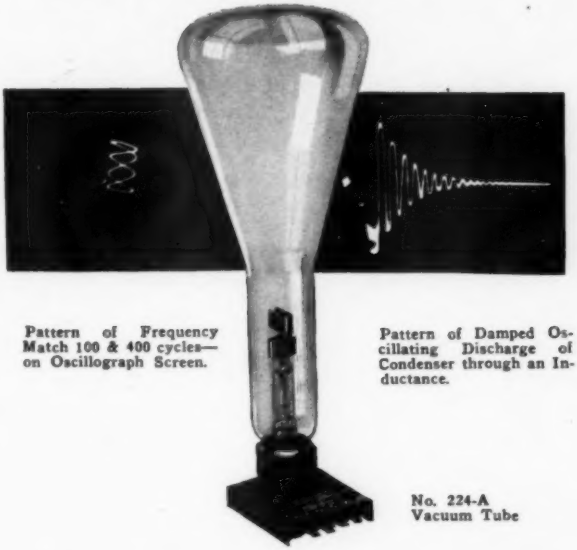

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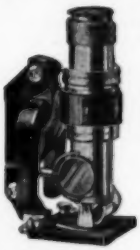

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